CHARACTERIZATION OF EARTHEN ARCHITECTURAL SURFACE FINISHES FROM KIVA Q, CLIFF PALACE, MESA VERDE NATIONAL PARK COLORADO

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INTRODUCTION

Earthen architectural surface finishes pose a unique challenge to building materials conservators. Ephemeral in nature and intended as sacrificial protective coats for the underlying structure, these plasters were (and continue to be) applied as renewable building skins. Plain earthen finishes on most historic buildings in use do not necessarily require conservation *in situ*; it is possible to replace historic plasters in kind or with a compatible material without negatively affecting the visual and historic character of the building. In contrast, earthen finishes in association with archaeological or ruin sites require conservation strategies that must address techniques of treatment and protection, rather than replacement. These finishes are architectural evidence, resources for archaeologists and other scholars that provide important information regarding cultural, religious, and social issues of past civilizations. Regardless of the age of earthen finishes, whether they are to be replaced or conserved, material characterization is the first step in the conservation process. The objective of this thesis is the characterization and analysis of earthen surface finishes in Kiva Q within Cliff Palace, a 13th-century Ancient Puebloan cliff dwelling at Mesa Verde National Park, Colorado.

In 1994, the National Park Service entered into a cooperative agreement with the University of Pennsylvania to develop a system for documenting and preserving architectural surface finishes at Mesa Verde. A graphic conditions survey system was developed and tested at Mug House on Wetherill Mesa and subsequently at Cliff Palace on Chapin Mesa. Field surveys were translated into computer-generated drawings to interpret the condition of the centuries-old surface plasters, and to develop strategies of

intervention with respect to the environment and deterioration mechanisms at work within these structures. The drawings serve as records of current conditions, previous repairs and interventions, and as templates for documenting future surface conditions and conservation treatments. Additionally, these drawings are diagnostic tools for understanding the cause and rate of finish deterioration. The cooperative agreement between the National Park Service and the University of Pennsylvania has also resulted in two theses (including this one) in which earthen architectural materials at Mesa Verde have been characterized using analytical methods, with the goal of developing effective and appropriate conservation treatments for surface finishes.

Historically, archaeological investigations of plastered surfaces in Anasazi sites have focused on painted murals within kivas. Archaeologists were interested in the geometric and figurative designs painted on various plaster layers, and utilized ethnographic data obtained from modern pueblos to build hypotheses on the religious and social practices of the Ancient Puebloans based in part on the decorative schemes found in the kivas. Plasters were regarded as substrates, the canvas for painted designs, occurring one atop the other. Recently, plasters devoid of discreet painted designs have been recognized as space-defining elements of pueblo architecture, particularly within cliff dwellings where plasters were not necessarily applied to protect underlying masonry. Therefore, a new appreciation of surface finishes throughout Anasazi sites includes these plasters. Kiva Q in Cliff Palace is an example of a kiva having no dominant painted design on the most recent plaster layer. However, a hemispheric division is expressed with the plaster itself, raising questions about the kiva's role in relation to other kivas within the cliff dwelling. Additionally, finishes and colors were used preferentially

within the kiva to delineate different architectural elements, and possibly reflect symbolic meaning. This thesis addresses the use of surface finishes to communicate architectural hierarchies within the kiva, and may contribute information in testing possible relationships between architectural surface treatment, room use, and meaning. It also contributes to a potentially growing database of materials used through analytical methods of characterization.

Samples of surface finishes representing full stratigraphies were obtained from Kiva Q. These samples were examined using an array of analytical methods to characterize the constituent materials, including light microscopy, X-ray diffraction (XRD), scanning electron microscopy with X-ray analysis (SEM/EDS), and infrared spectroscopy (FTIR). Together with archival research and on-site observation, characterization was conducted with the following research questions in mind:

1. What is the composition of these finishes? Do they change through time as superimposed campaigns?
2. What colorants, aggregates and binders were used?
3. What was the appearance of the kiva over time?
4. Do the finishes suggest changes or continuities in treatment, use and meaning?

Chapter 2

HISTORY OF MESA VERDE

Mesa Verde is located in the Four Corners Region of the United States defined by the state borders of Utah, Colorado, Arizona and New Mexico. Mesa Verde is an impressive landmass, its dramatic northern escarpment abruptly rising 1,500 feet above the surrounding Montezuma Valley in southwestern Colorado. Sloping gently from an elevation of 8,500 feet on the North Rim to 6,500 feet on the southern end, Mesa Verde is not an unbroken tableland as its Spanish name implies. Scores of canyons divide the plateau into fingerlike projections referred to as mesas in their own right.[1]

Located on the eastern edge of the Colorado Plateau physiographic province, Mesa Verde was formed about 65 million years ago in the Late Cretaceous Period of the Mesozoic Era, when a great inland sea covered the Great Plains and much of what is now the Rocky Mountains. The Four Corners area was intermittently covered by water as the sea fluctuated in size over millions of years. During this time the oscillating sea deposited sandstones, siltstones, shales, limestones and coal covering the deep shale Mancos formation. Known as the Mesaverde group, this collection of deposits is made up of the Point Lookout, Menefee, and Cliff House formations (Figure 1). In the Tertiary Period of the Cenozoic Era the Mesa Verde plateau was uplifted about 2,000 feet and tilted in a bowl-shaped slope to the south. This uplift exposed the formations laid down by the ancient inland sea that are visible today. Erosion from streams running south-southwest cut through the sandstone layers of the Tertiary deposits and into the

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[1] James A. Erdman, Charles L. Douglas and John W. Marr, *Environment of Mesa Verde, Colorado* (Washington, D.C.: National Park Service, 1969), pp. 15-17.

Cretaceous shales, forming the fingerlike mesas characteristic of Mesa Verde.[2]

Volcanic activity was very influential to the geology of the area, forming many of the mountain ranges, including the San Juan Mountains. Furthermore, volcanic eruptions are responsible for deposits of bentonite, a clay mineral resulting from the alteration by weathering of volcanic ash, within all of the Mesaverde formations.[3] The mesatop soils of Mesa Verde are primarily wind-blown loess, although soils formed from weathered sandstone may be found in the higher reaches. Mesa Verde soils vary in carbonate content according to the carbonate content of the underlying sandstone. In the southern region of the mesa the soil surface is highly calcareous.[4]

The climate of Mesa Verde is classified as a semi-arid or steppe, and there are no streams or running rivers. Precipitation, annually totaling 14-18 inches, is in the form of snow in the winter and heavy thunderstorms in the summer. Tree ring and pollen data indicate that climate and vegetation have changed little in the past 600 years. The primary vegetation of Mesa Verde is the pinon-juniper forest, although the taller Douglas fir and Ponderosa pine occur in higher elevations and where moisture is abundant. Mountain brush and big sagebrush communities, outcroppings of diverse grasses, cactus and yucca, all flourish in the different plant zones of the mesa tops, canyons, peaks, and open glades of Mesa Verde. A moderately diverse wildlife is supported by the numerous habitats of Mesa Verde, including Rocky Mountain mule deer, elk, bear, coyotes, rodents

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[2] Gilbert R. Wenger, *The Story of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1997), pp. 9-13.
[3] Mary O. Griffits, *Guide to the Geology of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1990), pp. 39-65.
[4] Erdman, Douglas and Marr, pp. 15-17.

such as chipmunks and cottontail rabbits, turkeys, migratory birds, lizards and tarantulas.[5]

2.1 THE ANCIENT PUEBLOANS

"Anasazi," a Navajo word meaning "ancestors of our enemies," was adopted by A.V. Kidder in the early twentieth century to refer to the prehistoric inhabitants of the Four Corners area, the culture centering in the drainage of the San Juan and Little Colorado Rivers, from about 700 B.C. to the arrival of the Spaniards in the Southwest. Currently the term has been rejected by many modern Pueblo Indians, who view themselves as descendants of the Anasazi. Today scholars and the National Park Service prefer to call the Anasazi the Ancient or Ancestral Puebloans. Significant Ancestral Puebloan sites include Mesa Verde, Chaco Canyon in New Mexico, Hovenweep in Utah and Colorado, and Canyon de Chelly in Arizona (Figure 2). The cultural signatures of the Ancient Puebloans are the kiva and unit pueblos with their orientation to the south and southeast, the characteristic grey-and-white, black-on-white, and corrugated pottery, and distinct burial patterns. During the 1927 Pecos Conference a cultural chronology was established, dividing the history of the Ancestral Puebloans into three Basket Maker stages and six Pueblo stages (Figure 3).[6] With respect to this time framework, the Ancient Puebloans occupied Mesa Verde from the third Basket Maker stage through the third Pueblo stage.[7]

The Ancient Puebloans descended from the older Paleo-Indians of the Archaic

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[5] Wenger, pp. 15-25.
[6] William M. Ferguson and Arthur H. Rohn, *Anasazi Ruins of the Southwest in Color* (Albuquerque: University of New Mexico Press, 1987), pp. 1-4.
[7] The terminology used here respects the chronology established by the Pecos Conference, while utilizing the Roberts adaptation, as well as classifications specific to Mesa Verde as outlined by Wenger.

Period, who were nomadic hunter-gatherers. The chronology established by the Pecos Conference and adapted by other scholars traces the evolution of a culture from highly mobile hunter-gatherers to sedentary farmers through enduring material artifacts such as tools, clothing, baskets, ceramics, and architecture. Basket Maker I is a conjectured stage spanning almost 3,000 years representing the end of the Archaic Desert Culture, terminating at about 700 B.C. Basket Maker I people were hunter-gatherers who used stone tools and projectile points, and whose camps featured hearths. Basket Maker II (700 B.C.-450 A.D.) is characterized by the large quantity of baskets found in sites of this period. People of this stage lived under rock overhangs, and circular pithouses are found in some areas. This stage is also characterized by farming of maize and squash in combination with hunting and seed gathering, and tools included spear throwers known as atlatls, as well as darts and drills. In the terminology developed by Frank Roberts in 1935, Basket Maker I and Basket Maker II are combined and renamed simply Basket Maker (A.D. 1-550), because of the lack of evidence for the Basket Maker I period.

The first evidence of human occupation at Mesa Verde falls within the classification of Basket Maker III (A.D. 550-750). People of this era climbed the escarpment of Mesa Verde and lived on the mesa tops. Also known as Modified Basket Maker, this stage represents a transition from nomadic life to an increased dependence on agriculture, resulting in a more sedentary lifestyle. While the use of high quality baskets persists, this stage represents the development of pottery, which probably grew from the practice of lining baskets with clay in order to make them water tight. Other important inventions of this era are the bow and arrow replacing the dart and atlatl, the domestication of turkeys and cultivation of corn, beans, and squash, and the construction

of permanent, semi-subterranean circular pithouse dwellings. The Modified Basket Makers also traded for goods from as far away as northern Mexico and the Pacific Coast.

The Pueblo I (A.D.700-900) and Pueblo II (A.D. 900-1100) stages are combined in the Roberts classification into the Developmental Pueblo stage. During this time rectangular aboveground *jacal* structures were built from poles lashed together with brush and faced with earthen daub, first as storage rooms, while the pithouses continued to serve as residences. By the Pueblo II stage, rectangular masonry buildings with contiguous rooms were used as dwellings while the pithouses took on the function of meeting places and workspaces. It was during this period that the kiva was developed from the pithouse as a fully subterranean room with a banquette, representing the cultural center of the pueblo. Agricultural systems became more sophisticated with the development of reservoirs, check dams, and irrigation systems. Painted and coiled, corrugated pottery increasingly replaced baskets in this period.

The Pueblo III stage (A.D. 1100-1300), also known as the Great or Classic Pueblo stage, was characterized by the large settlements of multiroom, multistory stone masonry pueblos with many kivas. Agriculture was central to maintaining these large population centers, and dry land farming techniques served the people well. At Mesa Verde the southern mesa tops continued to be cultivated, but the people moved to the alcoves below and constructed cliff dwellings above the canyons, including Cliff Palace. This period reflects the apex of Ancient Puebloan architecture, but the end of the Classic Pueblo stage is also the end of occupation of Mesa Verde by the Ancestral Puebloans.

The abandonment of Mesa Verde and other sites in the Four Corners region around 1300 A.D. is known as the Great Migration. The Ancient Puebloans left the large

pueblos and moved south along the Rio Grande Valley to present-day New Mexico and Arizona. The reasons for this exodus are not clear, but a combination of environmental and social pressures probably forced the disintegration of large settlements. The Pueblo IV or Regressive Pueblo stage (A.D. 1300-1540) represents the emergence of Modern Pueblo Indian sites as important cultural centers and the arrival of Spaniards in the Southwest. In the Pueblo V stage (A.D. 1540-1850), Modern Pueblo Indians were subjugated by the Spanish, Mexican and early New Mexican explorers and settlers. The Pueblo VI stage begins in 1850 and continues to the present.[8]

2.2 EUROPEAN CONTACT: Conquistadors, Cowboys and Collectors

Mesa Verde, abandoned by the Ancient Puebloans, remained untrammeled by human feet for almost 600 years. Spanish explorers probably passed near enough to give the "Green Table" its name, but Franciscan friars and other eighteenth and nineteenth-century travelers from Spain did not venture to its heights. Anglo encounters with Mesa Verde were sparse, consisting largely of a few expeditions by photographers and reporters, until Richard Wetherill and Charles Mason stumbled upon Cliff Palace in December of 1888. The Wetherill family had a nearby ranch and, enjoying good relations with the nearby Ute Indians, wintered their cattle on Mesa Verde, which led to the discovery of many of the cliff dwellings. Richard Wetherill's interest in the cliff dwellings led to a lifetime search for more Ancient Puebloan "cliff-dweller" ruins that took him to Utah and New Mexico. Word of the Wetherills' find spread fast, sparking a flood of visitors guided by the Wetherills, who wreaked untold damage plundering the

[8]Ferguson and Rohn, pp. 1-17 and Wenger, pp. 27-75.

sites for artifacts. A noted collector was Gustav Nordenskiold of Sweden, who photographed and excavated the ruins he visited in 1891, and amassed a large collection that he took with him to Sweden. Nordenskiold, a scientist, produced work of high quality for the time. He published *The Cliff Dwellers of the Mesa Verde* in 1893, which included his photographs and observations of the ancient cities. His large acquisition of artifacts aroused the public ire and initiated a movement to protect the archaeological resources of Mesa Verde.[9]

2.3 MESA VERDE NATIONAL PARK

The public sentiment to protect the dwellings at Mesa Verde, brought on by the unstaunched flood of artifacts leaving the ruins, was just what Virginia McClurg needed. McClurg had visited the cliff dwellings in 1882, 1885, and 1886 as a reporter for the *New York Graphic*. From 1887 to 1906 she campaigned tirelessly to convince Congress and the American people to preserve the cliff dwellings of Mesa Verde. With the support of Lucy Peabody and of the Federation of Women's Clubs, she formed the Colorado Cliff Dwellers Association and negotiated with the Weminuche Ute Chief Ignacio to gain control over the cliff dwellings while the Utes retained grazing rights to the land.

In 1906 Virginia McClurg and Lucy Peabody's efforts paid off, with Congress authorizing the creation of Mesa Verde National Park. On June 29, 1906, President Theodore Roosevelt signed the bill creating the largest archaeological preserve, Mesa Verde National Park, nine years before the creation of the National Park Service.[10]

[9]Wenger, pp. 77-84.

2.4 ACCESS AND ARCHAEOLOGY: The Dual Missions of the Park

As an archaeological preserve, Mesa Verde National Park has the responsibility of serving the public in facilitating visitation, and serving science in conducting archaeological investigations. Preservation of the architectural remains serves both of these interests, and has been integrated into the Park's mission from the beginning.

For the first few years of the Park, a number of Superintendents struggled to create public access to the ruins along the remote trails. In the meantime, archaeological work was begun by Dr. Jesse Walter Fewkes of the Smithsonian Institution's Bureau of American Ethnology, who excavated and stabilized a number of cliff dwellings. Reliable roads facilitated public visitation to the Park, and in 1917 the ranger station was converted into the first museum inside a National Park. Superintendent Jesse Nusbaum directed excavations of both cliff dwellings and mesa top sites in the 1920's. By the 1930's visitation and exposure was inflicting enough damage on the ruins to necessitate a concerted park-wide stabilization program. In 1933 Earl Morris instituted the Ruins Stabilization and Repair Program, and Lyle E. Bennett led the Ruins Survey Program to record the repairs. James A. (Al) Lancaster succeeded Morris in 1934, and was head of the Ruins Stabilization and Repair Program until 1965. Archaeological excavations continued, culminating in the National Geographic Society-sponsored Wetherill Mesa Archaeological Project, an attempt to open Wetherill Mesa to visitors beginning in 1958 and continuing for seven years. More recently, small research projects are conducted in the Park, and a stabilization crew maintains and repairs sites and properties.

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[10] Ibid, pp. 85-87.

Chapter 3

ANCIENT PUEBLOAN ARCHITECTURE AT MESA VERDE[11]

Structures built by the Ancestral Puebloans during their occupation of Mesa Verde reflect cultural changes in resource exploitation and technology, represented by the transition from a hunter-gather to an agricultural society. The dynamic relationship between culture (population, kinship, economy, religion) and environment (climate, topography, ecology) affected the material culture of the Ancient Puebloans, including architecture. Mesa Verde architecture exhibits a curiously circular evolution of the semi-subterranean pithouse of the Modified Basket Makers, where the above-ground structure developed into the pueblo house, while the pit component evolved into the kiva (Figure 4).[12] These architectural forms developed as the Ancestral Puebloans moved from rock shelters to the mesa tops, then back to the shelter of the alcove cliff dwellings.

3.1 THE PITHOUSE

Modified Basket Maker pithouses, the first permanent structures built by the Ancient Puebloans at Mesa Verde, probably evolved from storage units used by earlier Basket Maker peoples. These storage units, or cists, consisted of holes dug into the ground, lined with rock slabs and covered with small logs and a flat stone. Pithouses of the later Modified Basket Maker stage were constructed by digging a shallow rounded

[11] Information about Ancient Puebloan architecture was obtained from a number of sources, including Wenger's *The Story of Mesa Verde National Park*, and various archaeological reports of Jesse Walter Fewkes, Arthur Rohn, Al Lancaster, and Watson Smith.

depression a few feet into the ground. A low bench often surrounded the pit circumference, and four wooden posts were set into this bench or into the floor of the pit. These posts, supplemented by sloping logs forming the walls, supported horizontal timbers making up the roof structure. Smaller logs, sticks, juniper bark, and mud were placed over the roof and walls to form a weatherproof shell (Figure 5).

The pithouse was separated into two rooms, the living area with a central hearth, and an antechamber with an opening in the roof to provide ventilation. Often, a storage area was added to the side of the larger living and sleeping area. A hole in the roof above the larger room provided access to the structure and a smoke hole for the firepit. From the pithouse, the Modified Basket Makers developed two aboveground structures: the granary, a food storage unit made of *jacal* (sticks woven together and bound with mud), and the *ramada*, a canopy providing shelter for work areas. These basic architectural forms led to the structures of the Pueblo stages to follow, and aspects of pithouse building, especially roof construction, persist to this day in contemporary Pueblo style architecture of the Southwest.[13]

3.2 THE PUEBLO

In Southwest archaeology, the word "pueblo" is used to refer equally to a chronological classification, a group of buildings within a particular type of village, and the people living in this type of village. In the Pecos Classification, the Basket Maker era is named for the prominent material artifact of the culture. In the context of material artifacts, it is interesting that the next major classification is not named Pottery Maker,

[12]Wenger, pp. 30-40.

but Pueblo. This designation reflects the importance of pueblo buildings, the construction of which requires the cooperative effort of a cohesive group of people. The transition from Modified Basket Maker to Developmental Pueblo traces the formation of large communities committed to living in one place for a long period of time.

The architectural form characteristic of the Pueblo stages is an above ground group of contiguous rooms arranged in a rectangular block. Roomblocks developed from the above ground structures of the Modified Basket Makers, combining the attributes of the pithouse, the granary, and the *ramada*. By this time the Ancient Puebloans had moved to the mesa tops to grow the majority of their food. As the communities of the Modified Basket Makers grew denser as a result of increased dependence on agriculture, dwellings crowded closer to one another, favoring a rectilinear configuration. Pueblo rooms were built on stone foundations with walls made of *jacal*, like the earlier granaries, and the roofs supported by posts recall the ramadas of the Modified Basket Makers. However, these rooms were dwelling units, not storage or work areas. Pithouse-like rooms continued to be constructed next to the roomblocks, where one pitroom might serve an entire village. These circular pitrooms, used as clubhouses and by special societies for ceremonial use, gradually took on the role of rooms named kivas by modern Hopi.[14] Pueblo roomblocks typically faced south, with storage rooms to the north and kivas to the south of the living rooms.

Increasingly sophisticated stone masonry replaced *jacal* construction during the Pueblo stage, and the Ancient Puebloans learned to build walls two to three stones thick

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[13] Ibid. and Ferguson and Rohn, pp. 25-28.
[14] Wenger, pp. 39-40.

to make multi-story roomblocks and tall lookout towers possible. These construction practices continued in the Classic Pueblo stage, when the Ancestral Puebloans of Mesa Verde moved to the cliff alcoves between A.D. 1150 and 1200.

These alcoves were formed by an erosional weathering process in the uppermost sandstones of the upper Cliff House formation. Water percolating through the porous sandstone stops where it meets a thin but impermeable layer of shale, then runs down along the shale layer until it seeps out at a canyon wall. At these seep points, the sandstone is worn away by mechanical and chemical processes. Rainwater combines with atmospheric carbon dioxide to form a weak carbonic acid, which dissolves the calcium carbonate cementing material of the sandstone. The sandstone disintegrates, and alcoves occur at these interfaces of the sandstone and shale. Deeper alcoves are formed where a layer of bentonite up to a foot thick occurs above the shale layer. Bentonite, a smectite clay, has a tendency to absorb water, resulting in a major increase in its volume. The resultant swelling of the bentonite layer causes pressure where it contacts the sandstone, speeding up the deterioration of the sandstone layer.[15] The villages of the cliff-dwelling Ancestral Puebloans were often constricted by the shallow spaces of the alcoves, and the architecture reflected the upward movement necessary to expand in the close quarters. The tall square and round towers of the Classic Pueblo period represent the apex of Ancient Pueblo architecture at Mesa Verde (Figure 6).

3.3 THE KIVA

The modern Hopi word "kiva" refers to a subterranean chamber used by special

societies for religious rituals and club activities. The term was adopted by archaeologists, who saw a strong link between the "cliff dwellers" and modern Pueblo peoples, and a similar link between Hopi kivas and the subterranean rooms in Ancient Puebloan villages of the late Developmental and Classic Pueblo stages. Ethnographic studies of modern Puebloans, mainly the Hopi, figure prominently in theories about the function of kivas in "cliff dweller" cultures. From these studies and excavations of Ancient Puebloan sites, archaeologists hypothesize that prehistoric kivas served a number of functions. Ritual use is assumed universally, based on the modern Hopi use, and because the role of seasonal ceremonies is viewed as increasingly important as the Ancestral Puebloans depended on successful crops to support large populations. A historic tendency to fit artifacts of unknown function into the category of religious use has influenced this point of view. However, a strong argument for the specialized use of Ancient Puebloan kivas is the presence of decorative surface finishes, often numerous campaigns of elaborate painted designs, in many kivas. If Ancestral Puebloan social structure was similar to that of the Hopi, Anasazi kivas were probably used as meeting places for men of the same clan, whose matrilineal culture obliged them to move to the houses of wives who might belong to a different kinship group. During the cold winters, kivas almost certainly were used as sleeping quarters for everyone.

The evolution of the kiva from the pithouse of the late Modified Basket Maker period was subtle, the distinction between the two more a matter of function than form. At Mesa Verde and elsewhere, the stone-lined and plastered pithouses anticipated the masonry kivas with plastered and decorated walls. The bench running the circumference

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[15]Griffits, pp. 69-70.

of the pithouse became taller as the pithouse became deeper, forming a feature called the banquette in the kiva. Masonry pillars, known as pilasters in the kiva, gradually replaced the vertical posts resting on the bench of the pithouse supporting the roof structure. The roof structure of the pithouse evolved from a post-and-beam configuration to a crib roof resting on the log or stone pillars, and the kiva shares the characteristic crib roof. The interior features of the pithouse and kiva are also similar, both having a central hearth, a ventilator, a deflector to prevent drafts from extinguishing the fire, and a cylindrical opening in the floor known as a sipapu to the modern Hopi (Figure 7). The sipapu represents the opening to the lower world from which the ancestors of the Hopi emerged. The antechamber of the pithouse was phased out in the single-room kiva, though a vestige persists in the form of ventilation shafts, tunnels leading to other rooms, and possibly the recess present in the southern end which imparts the characteristic keyhole shape of many kivas in Mesa Verde.

The most important difference between pithouses and kivas is the use of the room. Once pithouses ceased to function as dwellings and the Ancient Puebloans built above ground houses, these subterranean structures served specialized social and religious purposes. Kivas became communal rooms for small villages, and united discreet dwellings within large villages.

3.4 CLIFF PALACE

Cliff Palace, located on Chapin Mesa at Mesa Verde, is a Classic Pueblo site and the largest Cliff Dwelling in the Park (Figure 8). Built by the Ancient Puebloans in the latter half of the thirteenth century, the village is located in a very large west-facing

alcove and consists of buildings made of shaped sandstone blocks laid in earthen mortar. Much of Cliff Palace deteriorated during its abandonment and as a result of destructive pot hunting in the late nineteenth century, but many rooms are still well defined. Rectilinear and circular dwellings and storage rooms one to four stories high are arranged around plazas formed by the 23 kivas of the cliff dwelling. Estimates of the number of rooms originally in Cliff Palace range from 150 to 220.

Despite the notoriety of Cliff Palace, the most visited cliff dwelling at Mesa Verde National Park, relatively little research has been conducted there. In the summer of 1909, Dr. Jesse Walter Fewkes of the Smithsonian Institution Bureau of American Ethnology, noted ethnologist of the Hopi in Arizona, excavated and repaired the structures of Cliff Palace, leaving it "in such condition that tourists and students visiting it may learn much more about cliff dwellings than was possible before the work was undertaken."[16]. Indeed, students and tourists visited Cliff Palace, clamoring over the masonry walls and damaging the ancient structures. In 1934 James A. Lancaster carried out expert repairs of buildings in Cliff Palace, photographing the stabilization work of his crew. Fewkes and Lancaster left precious little written documentation of their stabilization work, and no archaeological investigations were carried out in Cliff Palace for over 80 years after Fewkes' publication.[17]

A general conditions survey of architectural surface finishes at sites including Cliff Palace at Mesa Verde National Park was carried out by architectural conservators Constance S. Silver and Jacqueline Gens in 1985, using photography and written

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[16] Jesse Walter Fewkes, *Antiquities of the Mesa Verde National Park: Cliff Palace*, Smithsonian Institution Bureau of American Ethnology Bulletin 51 (Washington, D.C.: Government Printing Office, 1911) p.9.
[17] David Roberts, "A Social Divide Written in Stone," *Smithsonian* February 1999, pp. 119-128.

documentation forms. In 1998 a detailed conditions survey of architectural surface finishes was carried out in Kiva K, Kiva Q, Room 121, and Rooms 71-72 of Cliff Palace as a part of the Conservation of Architectural Surfaces Program for Archaeological Resources (C.A.S.P.A.R.) project co-sponsored by the National Park Service and the University of Pennsylvania.

Recently, National Park Service archaeologists have begun to study Cliff Palace again, using research tools reflecting a different perspective on the relationship between researchers and native peoples of the Southwest. By the late twentieth century, the claims of modern Native American tribes to ancient Native American remains, sites and artifacts were increasingly recognized by the United States Government, resulting in more cooperation between tribes and Government agencies. Excavation of Native American sites decreased on public lands, and ceased to be a major research component at Mesa Verde.

The new tools of archaeology at Cliff Palace are tape measures, cameras, and computers. By studying the masonry of the structures, archaeologists can identify construction chronologies of the buildings in the dwelling. Dendrochronology, the technique of tree-ring dating developed in the early twentieth century and refined at Mesa Verde and other sites, is used to pinpoint dates of construction using original architectural timber specimens. The comparison of masonry styles and the documentation of wall interfaces within the cliff dwelling helps archaeologists and architects assemble a chronological history of the construction of buildings at Cliff Palace.

Recent research by Dr. Larry Nordby of the National Park Service has focused attention on the types of structures at Cliff Palace, raising questions about the number of

people who could have lived there and how Ancestral Puebloan society was organized at Cliff Palace and elsewhere at Mesa Verde. Based on his documentation of Cliff Palace, Nordby counts a maximum of 28 residential rooms and 23 kivas, meaning that the remaining 100 rooms were used for storage or communal gathering purposes. Nordby hypothesizes that the people living permanently in Cliff Palace were a caretaker population maintaining the site for a larger population visiting several times a year. This theory of social organization runs counter to the historic perceptions of the Ancient Puebloans as a decentralized culture of autonomous villages. In his structural documentation and study, Nordby observed an interesting feature of Cliff Palace that could reinforce the theory of specialized social function for the village. This feature, a continuous zigzag wall dividing the cliff dwelling in half, suggests a possible social partition, a cultural division like the moieties of modern Puebloans such as the Winter and Summer clans of some pueblos of the Rio Grande Valley.[18] Whatever the significance of the dividing wall, it is interesting that Kiva Q, located near the center of Cliff Palace, visually echoes this division in its unusual bichrome uppermost application of plaster.

3.5 KIVA Q

In his 1909 survey and excavation Fewkes divided Cliff Palace into quarters along a north-south axis, and identified four tiers or terraces of the cave floor indicating different levels where structures of the village were built (Figure 9). Kiva Q lies in the Old Quarter on the 4th Terrace, adjacent to Rooms 71-74 that Fewkes named the Speaker-

[18] Ibid.

chief's House.[19] The kiva is set against the recess created by the Speaker-chief plaza and Kiva R, which lie among fallen boulders and rock fill around which Kiva Q was built. The masonry of Kiva Q is of very fine quality, consisting of well-dressed stones laid in earthen mortar, some of which have pecked surfaces. In some places the mortar protruding from between the stones was spread over the masonry, resulting in an extruded smooth mortar joint described by Silver as 'defacto plaster.' Fewkes found Kiva Q in fair condition, apart from the destroyed west wall of the kiva. Like all other kivas in Cliff Palace, the roof of Kiva Q was long gone. The top of the kiva and the remaining pilasters required some stabilization, which Fewkes performed and Lancaster rebuilt.

The surface finishes of Kiva Q, where extant, vary in condition. The finishes of the south end are in better condition than those elsewhere, but most of the plaster exhibits areas of flaking and detachment from the masonry, as well as delamination between layers of finish. The walls of Kiva Q were finished several times with washes and plasters from earthen materials such as soil and sand, and added color using inorganic and organic colorants to delineate architectural and symbolic elements. The most distinctive feature of Kiva Q observed in the uppermost layer of plaster is a hemispherical division of the kiva running from the top of the banquette to the floor through the center of a niche (Figure 10). This dividing line is created by the interface of the two different shades of reddish-brown plaster used to cover the north and south halves of the kiva. Although the line on the east wall is clear, a corresponding line cannot be confirmed on the destroyed west wall.

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[19] Fewkes, p. 46.

Chapter 4

EARTHEN ARCHITECTURAL SURFACE FINISHES AT MESA VERDE

Earth was the primary material employed by the Ancestral Puebloans in the creation of architectural surface finishes. Long employed as a building material, earth formed the walls for storage cists and pithouses, and provided stability to masonry units when used as mortar.

Earthen plaster at Mesa Verde probably developed from early attempts to seal and waterproof storage spaces, domestic structures, and containers in the Basket Maker and Modified Basket Maker periods. Plaster protected the exterior of pithouses and pueblo buildings from the destructive effects of rain, often coming in violent summer downpours, as well as wind and snow. These plaster surfaces would need to be renewed periodically as they weathered, creating a cycle of periodic renewal. Earthen finishes were applied to the interior of later pithouses, where plaster coated the floor, firepit and walls. Mural painting appears in Developmental Pueblo structures, clearly indicating symbolic as well as practical functions of these interior finishes.

As the Ancient Puebloans at Mesa Verde moved to cliff dwellings during the Classic Pueblo period, plaster became less important as a protective finish in the sheltered villages. Indeed, the adoption of stone masonry construction allowed the exclusion of surface finishes where alcoves shielded structures from rain and snow. However, earthen surface finishes continued to be used on both exterior and interior surfaces. Plasters and washes still coated exterior walls outside of the drip edge of the alcove to prevent the

earthen mortar from eroding, but finishes on protected buildings appear to have had a more specialized use. The primary function of these plasters helped to define architectural space. While upper wall surfaces of these sheltered rooms remained bare, the ground floor walls of rooms surrounding a kiva plaza were often finished, physically and visually uniting the rooms to create a space centered on the kiva. These plazas were the focal point of Ancestral Puebloan cliff dwelling units where outdoor activities were probably centered; the rooms themselves served as storage spaces or sleeping quarters.

The interiors of kivas display the most elaborate surface finish treatments, including geometric mural decorations that are assumed to be of religious importance. These decorations are similar to pottery designs, and reflect an important link between pottery development and the refinement of mural painting. The Ancient Puebloans produced high-quality ceramics, the result of hundreds of years of technological improvements in constructing and firing pottery. Such advances took place as they gained an increased understanding of the clays and other earthen constituents of the ceramics, so it is no accident that plasters became increasingly sophisticated as well. Consequently, all the earthen architectural surface finishes of the cliff dwellings at Mesa Verde are extremely durable, many surviving despite 700 years of exposure to the elements and a combination of neglect and destructive attention. An understanding of earthen finishes at Mesa Verde must begin with an examination of the types of finishes present and their constituents.

4.1. PLASTERS AND WASHES

Studies that have focused on decorative finishes at Ancient and modern Pueblo

sites, such as the work of Watson Smith,[20] have described these materials as plaster and paint. A recent descriptive lexicon associated with a condition assessment of architectural surface finishes at Mesa Verde, developed by the Architectural Conservation Laboratory at the University of Pennsylvania, has identified these components as plaster and wash, defined as finishes equal to or less than 1 mm thick (washes), or more than 1 mm thick (plaster). The latter nomenclature is adopted here.

4.1.1 *Plasters: Soil and Water*

Ancestral Puebloan plasters, as discussed above, are earthen finishes. As such, these plasters are comprised of soil and water. Soil is defined as an unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. The composition of soil in a given area varies according to the topography, climate, vegetation, and parent rock of that area, and the time involved in the formation of the soils.[21] Soils may be described according to their geotechnical classification and their mineralogical composition.

Geotechnical classification is based solely on particle size, where soil constituents are grouped according to their grain diameter into the categories of gravel (60mm-2mm), sand (2mm-60μm), silt (60μm-2μm), and clay (smaller than 2μm).[22] The relative proportions of these constituents, known as the particle size distribution, determine the

[20] Watson Smith, *Kiva Mural Decorations at Awatovi and Kawaik-a*, Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, Vol. 37 (Cambridge: Peabody Museum, 1952).
[21] Jeanne Marie Teutonico, lecture, University of Pennsylvania, October 2, 1997. For discussions on soil also see Rodney Cotterill, *The Cambridge Guide to the Material World* (Cambridge: Cambridge University Press, 1989) pp. 132-133 and Giorgio Torraca, *Porous Building Materials: Materials Science for Architectural Conservation*, 2nd Edition (Rome: ICCROM, 1982) pp. 95-99.
[22] The particle size specifications noted here are those of the European Classification, which differs slightly from ASTM and other standards.

physical properties of a soil, and thus its suitability as a building material. Sand acts as the aggregate and imparts compressive strength, shrinkage control, texture, and color to earthen architectural materials. Sandy soils have a coarse texture and are dimensionally stable, but are not particularly cohesive. Clay acts as the binder, giving cohesion to the soil particles. Clayey soils are sticky and plastic when wet, making them very workable with excellent adhesive properties, but they tend to shrink and crack upon drying. Silt particles are secondary binders and bulking agents. High-quality earthen architectural materials, especially plasters, utilize soils having a good but often fine particle size distribution, with enough clay particles to be cohesive and enough sand fraction to add strength and control cracking.

The mineralogical composition of soils also affects their physical properties. Clay mineralogy is especially important. Clays, secondary minerals produced by the weathering of certain rocks, are the most abundant minerals at the earth's surface. Clay minerals consist of aluminosilicates such as feldspars and micas, and silicate-bearing ferromagnesium minerals from the olivine, pyroxene, and amphibole groups. Clays, particles less than 2μm in size, are formed from these rocks through physical and chemical weathering processes. Clays are classified as layer or sheet silicates, consisting of a sheet of corner-linked tetrahedral silicate molecules (SiO_4) and a sheet of edge-linked silicate molecules forming octahedra. Several hundred of these units or wafers are stacked to form a clay crystal approximately hexagonal in shape.[23] The three main groups of clays are kaolinite, illite, and smectite (formerly montmorillonite). These clays are distinguished by their lattice structure and chemical composition, which determine

their physical properties and behavior when exposed to liquid.

Illite and smectite wafers are made up of two layers of silicon oxide (SiO_2, or silica) with one interposing layer of alumina (Al_2O_3). These clays carry a negative surface charge and hydroxyl (OH^-) groups because of impurities, such as iron, substituting for silicon and aluminum. Positive ions are trapped between layers, and water molecules attracted by the hydroxyl groups penetrate the crystals, increasing the distance between layers and resulting in a swelling of the clays. The clays shrink in dry atmospheres when water is lost. A clay that swells and shrinks according to the presence of interstitial water is said to be an active clay. Of the two clays, illite is less active. Although it is more electronegative than smectite and attracts potassium ions in the silica layer, the attraction between the layers of illite is stronger because of the presence of calcium, resulting in less swelling in the presence of water than smectite.[24] Smectite, the most active of the three clay types, has the smallest crystal size (0.02μm). Elemental substitution occurs in the alumina layer, where iron and magnesium ions are attracted.

Kaolinite is a very pure clay, and the most stable of the three clay types. Kaolin wafers are made up of a layer of silica and a layer of alumina, and contain no impurities that would impart a negative charge. As a result, kaolinite does not attract water between the layers, making it a non-expansive, inactive clay. Water attracted to the surface of all clays allows them to slide easily over one another, giving clays the property of plasticity and workability. Kaolinite is a desirable clay constituent of a soil used as an earthen architectural finish because it has less tendency to shrink and cause cracking.

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[23] Cotterill, p. 132 and Duane M. Moore and Robert C. Reynolds, Jr., *X-ray Diffraction and the Identification and Analysis of Clay Minerals* (Oxford: Oxford University Press, 1989) pp. 3, 102-103.
[24] Torraca, pp. 95-96.

In addition to soil, earthen architectural materials may contain a number of additives that enhance physical or visual properties. Organic additives such as dung, blood, animal glues, and urine improve cohesion, and fibrous materials like grass and straw aid even drying, prevent cracking, and improve tensile strength. Inorganic additives (which may not be physically added but occur naturally) include calcium carbonate in the form of chalk or lime, which improves set, hardness and durability. Colorants in the form of inorganic pigments may be added to impart a desired color, or may occur naturally depending on the presence of iron, copper, or other minerals. Although various additives may be mixed into earthen architectural materials, the soil provides the majority of the physical properties. Consequently, soil constituents may be manipulated by selection and sifting to produce optimum characteristics of strength, plasticity, smoothness, etc., depending on the desired application of the earthen material. Mud bricks require a generous proportion of sand to impart the compressive strength necessary to their structural function, while earthen plasters demand the qualities of workability, low shrinkage and smoothness.

Earthen plasters at Mesa Verde reflect the mastery of soil mechanics achieved by the Ancient Puebloans. Hard, smooth, and durable, these plasters were most certainly manufactured through careful grading, selection and manipulation of the soil constituent. The task of identifying possible organic additives used is problematic, as these materials would have decomposed considerably in the intervening centuries. More easily answered are the question of methods of application and finishing of these plasters.

An interesting form of plaster employed at Cliff Palace and other cliff dwellings is an adaptation of the bedding mortar, where, protruding from the masonry courses, it

was smoothed over the surrounding wall. This finish, referred to as 'extruded smooth' or 'defacto plaster,' was often used in discreet areas as a filler for uneven joints or a partial surface-leveling coat. Applied plaster was usually spread on irregular stone masonry in relatively thick layers as a leveling coat to create a level and continuous surface. The plaster was worked smooth by hand using a circular motion, and a tool such as a stone or potsherd may have been used to create a polished finish. In kivas, layers of plaster were repeatedly reapplied for various reasons discussed below (see 4.2).

4.1.2 *Washes*

A wash is "a discreet layer (or layers) of thinly applied finish of any color, usually 1mm or less in thickness, which is applied directly over the masonry or applied plaster."[25] This term may be related to a finish described in a 1957 article written by Edwin R. Littmann on Meso-American mortars, plasters, and stuccoes where he defines a wash coat as "a coat of plaster which, because of its thinness, was probably applied by means other than trowelling... Such coats are usually less than 1 mm thick."[26] Where Littmann acknowledges paint as a separate finish category and refers to mural paintings, the University of Pennsylvania lexicon abandons the term 'paint' and adopts an approach defining plaster and wash as a function of thickness. Plasters and washes are categorized by where they appear in the architecture as discreet elements such as dados, fields, auras, floor bands, and wall bandings. Designs are discreet images or repetitive motifs applied onto or inscribed into the plaster and washes, and may themselves be washes, or incised

[25] "Condition Assessment of Architectural Surface Finishes, Mesa Verde National Park, Mesa Verde, Colorado: The Architectural Conservation Laboratory/University of Pennsylvania," (Philadelphia, 1999).

or impressed elements.

Regardless of the terminology, a distinguishing characteristic of a wash is often color, which may be treated in an analogous manner to paint as described in other studies of Ancient Pueblo finishes. This being the case, Watson Smith's 1952 study is an exemplary presentation of pigments used in kiva mural decorations in Arizona. A pigment is composed of finely ground insoluble materials that display color. The paint characterizations were carried out by some of the leading scientists of the time, who utilized microscopy, spectroscopy, and chemical analysis to identify the pigments in these ancient finishes. All the pigments were identified as inorganic minerals, except for black, which was derived from a variety of organic sources. Important colors in the study of finishes at Cliff Palace include black, white, and red. These pigments are described in Smith's study as follows:

> Black: The use of black was very common, but the constituents from which the pigment was made seemed to vary considerably. Almost all the samples tested proved to contain some form of carbon, although it was not always possible to determine its original source. A few samples were clearly charcoal, as evidenced by the visibility under a microscope of woody structure in some particles. Other samples were apparently bone black, since they gave positive tests for phosphates. And still others were unidentifiable forms of carbon.
> The possibility of mineral constituents in a few of the black pigments exists, also. One sample that contained carbon also gave a positive test for iron; and another appeared to contain no carbon but was composed of rod-like crystals suggestive of a manganese mineral.
>
> White: As in the case of black, the white pigments appeared to derive from a variety of sources. A large number consisted chiefly of siliceous matter or of kaolin, which in many instances were both present. This would undoubtedly be the white sandy clay that

[26] Edwin Littmann, "Ancient Mesoamerican Mortars, Plasters, and Stuccoes: Comacalco, Part I," *American Antiquity* Vol. 23 No. 2 (October 1957) p. 136.

occurs in Cretaceous beds underlying the Antelope Mesa. At least one sample contained silica and gypsum, also probably a natural substance. One sample gave positive tests for calcium and carbonate, and was thus identifiable as chalk.

Red: Like the yellows, the reds occur in several shades, but all seem to be derived from red iron oxide of the mineral hematite (Fe_2O_3), or from clay or sandstone containing it. The use of hematite is corroborated by the discovery of numerous lumps of the raw mineral in the debris filling various rooms and kivas.[27]

While the determination of pigments used in Anasazi decorations can be straightforward, the identification of other finish constituents is largely speculative. In most cases, pigments make up a larger percentage of the finish than the binder does. If the Ancient Puebloans used organic binders, as Smith suggests from ethnographic evidence gathered from modern Puebloans (resins or gums from trees, oils or polysaccharides from vegetable sources, or proteins from animal glues),[28] the detection of these fugitive materials would be difficult in the 700-year old finishes. The use of kaolin as a pigment suggests that fine clays could also have functioned as binders as well as calcium carbonate as an accessory mineral.

The binder and the carrier form the vehicle for the pigment or other colorant in a finish. The carrier, usually a volatile solvent, imparts fluidity to the finish and facilitates the application of the finish to a surface before it dries. In the case of clays, water acts as a dispersant for the clay and silt particles, allowing these washes to be applied to a surface and dry forming a thin brittle film.

Artifact evidence suggests the ancient inhabitants of Mesa Verde manufactured

[27] Smith, pp. 23-24.
[28] Smith, pp. 30-31.

colored washes by grinding naturally occurring mineral pigments into a powder using a mano and metate, then mixing the pigments with a base. The base was probably a thin clay-water slurry, which would enable the wash to be spread over a large area. Washes were applied with a variety of tools, including animal skins or stiff brushes which left striations that are still visible today. Hands and fingers also served as applicators, leaving characteristic dots and handprints that comprise many designs and motifs at Cliff Palace.

4.2 KIVA FINISHES: APPLICATION AND RENEWAL

Architectural surface finishes were frequently reapplied and renewed by the Ancient Puebloans, and this phenomenon is most pronounced in kivas. The number of finish layers observed in a kiva can be larger than the number of years of use postulated for the kiva. Smith outlines five probable reasons for the renewal of plaster coats in kivas:

1. Occasional partial disintegration or collapse of parts of the wall or plastered surface

2. The desirability of refurbishing the surface in order to obliterate an existing layer that has been blackened by soot

3. A customary periodic renewal in the nature of "spring cleaning"

4. The ceremonial necessity or practice of obliterating or secreting a sacred object after it has served the religious purpose or rite for which it was made[29]

The scenarios outlined by Smith provide a framework for the examination of kiva plaster stratigraphies and overall schemes. In the first case, the plaster may be classified as a repair, and will be a thick surface-leveling coat. The second scenario is problematic,

as Smith admits, because it is not clear that the level of soot blackening he observed could have been caused by the hearth fires in everyday use. Such a uniform deposition of soot was more likely deliberate, achieved by the combustion of fuel that would produce large amounts of smoke. A sooted surface was therefore indicative of an application method created for a specific purpose, such as vermin-proofing the wood roof, the by-product of which being the production of a black color field. The third, "spring cleaning" scenario implies a seasonal pattern of finish renewal. This phenomenon would be observed when the number of finish layers far exceeds the number of postulated years of use, and recurring motifs could be observed at regular intervals. The fourth reason for finish renewal, obliteration and creation of ritual images, may manifest itself in the stratigraphy as a series of alternating design layers. Obliteration may take the form of scratches over designs, manifested as gaps within a finish layer and over washing. Again, the number of finish layers may approximate or exceed the number of years of occupation. If ritual images were completely obliterated through the removal of entire finish layers by rubbing or scraping, detection would be difficult within stratigraphies.

4.3 DETERIORATION OF EARTHEN SURFACE FINISHES

Earthen surface finishes at Mesa Verde cliff dwellings, though partly protected by the alcoves, were subject to a number of deterioration mechanisms during the ancient occupation. Moisture destroys the integrity of earthen finishes, dispersing the matrix that cements the grains of the finish. Water in the form of rain and melting snow can

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[29] Smith, pp. 19-20.

mechanically erode earthen materials, while rising damp moving through the pores of earthen finishes through capillary action brings other forms of deterioration. Trapped water softens and weakens the finishes, carries soluble salts which crystallize and recrystallize during wetting and drying cycles, and expands and contracts during freeze/thaw cycling. Ancient finishes also deteriorated through abrasion during daily activities. Poor manufacturing or application processes affecting a finish's ability to adhere to masonry or other finish layers can also contribute to deterioration.

Post-occupational deterioration mechanisms include the same water-borne phenomena of the occupational period, but conditions arising from abandonment, excavation and visitation contribute to the deterioration of the earthen surface finishes. After the Ancient Puebloans left the cliff dwellings, the buildings and rooms began to deteriorate as roofs caved in and masonry walls crumbled. Rooms filled with roof material and wind-blown fill. This fill trapped moisture next to the walls, and served as havens for plant growth and animal habitation. Plant roots infiltrated the finishes, sometimes growing between finish layers and separating them from one another or the masonry substrate. Rodents nesting in the room fill burrowed into the walls and abraded the surface finishes. Birds roosted in the remote cliff dwellings, depositing guano on the walls.

Excavation of the cliff sites caused untold damage, not only from the destructive disturbances of digging and blasting, but from the removal of the room fill. Although the deposition of fill led to the problems described above, the fill also had the benefit of partially stabilizing the microclimate of the rooms, minimizing the effects of variations in

temperature and moisture content. Once the rooms were uncovered, surface finishes began to dry out rapidly, leading to salt efflorescence. The earthen finishes were once again subject to variations in temperature and humidity, resulting in freeze/thaw and salt crystallization cycles.

The protection and management of Mesa Verde's resources as the result of the formation of the National Park proved to be a mixed blessing for the surface finishes of the cliff dwellings, at least at first. While structural repairs were done on the cliff dwellings in preparation for visitation, surface finishes were not actively conserved (save for the improvement of sheltering room walls). In the early days of the Park, tourists were given unlimited access to some of the cliff dwellings, such as Cliff Palace. Damage from the high volume of visitors included abrasion and detachment of finish layers. Human destruction was significantly reduced once access to the cliff sites was restricted. However, surface finishes are still subject to environmental stresses.

Recently, Mesa Verde National Park has made a commitment to preserve earthen architectural surface finishes within some of the heavily visited cliff dwellings through documentation and conditions assessment, materials conservation treatments, environmental monitoring, and testing of protective backfilling systems. These actions, designed to protect the resources of the Park for future generations, reflect a philosophy of preservation through minimal intervention.

Chapter 5

CHARACTERIZATION OF EARTHEN SURFACE FINISHES AT KIVA Q, CLIFF PALACE: METHODOLOGY

5.1 SAMPLING

23 samples were collected from Kiva Q for the purpose of analyzing the materials and documenting the significant spatial, architectural and decorative elements of the kiva. Samples of complete stratigraphies, from the masonry substrate to the uppermost (last) campaign, were taken from the pilasters, banquettes, walls, and niches of Kiva Q to determine overall architectural treatments and hierarchies. Additional samples were taken at pilaster, banquette and floor junctures to determine the relation between adjacent architectural features. Samples were also collected where visible discreet designs indicated the increased likelihood of finding applied finish motifs in association with specific stratigraphies. (See Appendix A for sample list and Appendix B for sample map and visible design elements.)

5.2 DOCUMENTATION AND RECORDATION

The University of Pennsylvania internship at Mesa Verde and the field activities of the C.A.S.P.A.R. Project in the summer of 1998 provided the opportunity to observe, evaluate, and record the condition of prehistoric earthen architectural surface finishes in several cliff dwellings. The conditions survey of Kiva Q produced by field school participants is a resource and a guide to past stabilization efforts and past and present conditions of the masonry finishes of the kiva (See Appendix C). Few finish campaigns

are visible to the unaided eye in Kiva Q, but on-site observations of the kiva are invaluable to understanding the architecture.

5.3 ARCHIVAL RESEARCH

The primary resources that proved the most valuable in researching this thesis are archaeological reports and historic photographs. While published scholarly works on Cliff Palace and Kiva Q are scarce, many studies of Mesa Verde and its environment are available and useful to the analysis of earthen architectural finishes. In the study of archaeological sites, it is important to extend research tools broadly among scientific disciplines and deeply into prehistory. Mesa Verde geology provides clues for possible sources of materials and the properties of finishes manufactured with local soils. Researching the cultural, environmental, and ecological history of Mesa Verde provides a perspective on how the Ancestral Puebloans related to the resources available to them and how these resources were utilized in the development of the architecture.

5.4 ANALYSIS

The principle methodology employed in this research is based on the physical and chemical analysis of samples collected from the field. The samples were analyzed to obtain information on several levels in order to describe and characterize the finishes to the greatest extent possible. Visual examination techniques are an important component of the methodology. By observing the macromorphology of the samples, the sample stratigraphies provide a means of examining the sequence of finishes employed in the kiva through time, as well as distinct design schemes at specific times (See Appendix D,

E). At a smaller scale, the micromorphology of the samples holds clues to the physical properties of the finishes and their possible sources and manufacturing processes through the examination of the microfabric, i.e., matrix and aggregate. Instrumental and chemical analyses provide information about the chemical composition of the plasters and washes, reveal the nature of the clays and other compounds in the matrix that determine the performance and properties of the plasters, and identify the pigments in the washes.

5.4.1 *Light Microscopy: Opaque Sections and Thin Sections*

Theory

The visual analysis of the samples from Kiva Q consists of the microscopical examination of the samples in section to clarify stratigraphic relationships. These stratigraphies represent the sequential layers of plasters and washes applied to the kiva surfaces as well as other deposits such as soot. Opaque sections, also known as cross sections, are examined in reflected light and are used to identify physical properties of the stratigraphies such as layer number, color and texture. Cross sections are created by embedding a sample in mounting resin, cutting it with a saw, and polishing the face of the section. Cross sections can be several millimeters thick and do not permit light to pass through, but finer characteristics, such as porosity and particle size and shape, may also be discerned.

Thin sections are made by polishing the face of a cross section to a thickness of about 30μm, permitting light to pass through the sample. The use of transmitted light in the examination of thin sections utilizes the optical properties of minerals to identify materials in the sample. Optics is the study of the interaction of visible light with matter.

When light (understood in this case to have wave-like behavior) moves through most media other than air, it is slowed and refracted. While the frequency of the light remains the same, the wavelength of the light changes as the velocity changes. The observed behavior of light passing through materials can be used to identify minerals in a sample. Light may also be manipulated before it reaches the sample. Ordinary light vibrates in all directions perpendicular to the direction of propagation. Light may be polarized, or made to vibrate in a single plane; this is known as plane polarized light. When two waves of plane polarized light vibrate at right angles to each other, this is known as cross polarized or circularly polarized light.[30] Polarized transmitted light is used to identify minerals according to their behavior under these conditions, which depends on their crystallography, refractive index, and optic axes.

Method

Thin sections for all 23 samples were prepared by D.M. Organist Petrographic Laboratory of Newark, Delaware. Because of the fragility and water-sensitivity of the earthen finishes, the samples were embedded in an epoxy resin before polishing. Still, a significant amount of material loss occurred in many of the samples. The thin sections were examined under transmitted light using a Nikon Optiphot 2-Pol polarizing light microscope to identify materials through optical mineralogy. This was useful to identify individual minerals in the matrix and aggregate within finish layers. This microscope is also equipped with an ocular micrometer that was calibrated with a stage micrometer to measure the thickness of finish layers in some samples.

The stratigraphy of the thin sections was analyzed using an Alphaphot 2 Y2

[30] William D. Nesse, *Introduction to Optical Mineralogy* (Oxford: Oxford University Press, 1991),pp. 3-13.

microscope equipped with a quartz halogen DDL projector lens Darklite Illuminator.™ Examination of the thin sections under this illumination gave a clear image of the layer structure of the samples and realistic color representation. The micromorphology of key samples was characterized by describing the coarse and fine fraction in terms of color and texture, particle size, shape, and sorting, and other visual characteristics (see Appendix F). Stratigraphies identified under these light conditions were used to build speculative temporal finish sequences for the kiva.

The thin sections were photographed at 25x and 100x magnification using a Zeiss Axiophot MC100 polarizing light microscope. Dr. Gomaa I. Omar of the Department of Earth and Environmental Sciences at the University of Pennsylvania photographed all of the thin sections in plane polarized and cross polarized light. The photomicrographs were examined to characterize the plaster matrix and aggregate. A statistically significant number (30) of aggregate grains was measured in each photomicrograph with a millimeter ruler to quantify the grain sizes of the aggregate. Because the samples collected in the field were small, no geophysical tests could be undertaken to perform a particle size analysis. These grain measurements, together with the micromorphological examination, serve to quantify the coarse fraction (see Appendix G).

Cross sections were produced to provide additional information on layer structure for those samples whose stratigraphies were compromised during thin sectioning. Portions of samples 1, 3, 4, 6, 10, 11, 13, 16, 18, 19, 20 and 21 were first consolidated with 5% w/v Acryloid B-72 (Ethyl Methacrylate) in acetone. The samples were then embedded in BioPlast™, a proprietary polyester methacrylate resin polymerized with a methyl ethyl ketone peroxide catalyst. The embedded samples were sectioned with a

Buehler Isomet™ low speed saw to reveal the cross sections. Because sample loss was a concern with the thin sections, the cross sections were not polished.

Observations

Examination of the thin sections revealed the composition of the matrix and aggregate of the samples. The matrix, or paste, of the samples consists of the fine clay and silt fractions, the particles of which are too small to be resolved without specialized microscopical equipment. In general, the paste consists of tan, orange, brown, black, white and yellow particles which combine to give the plasters and washes their overall buff, tan, reddish brown, red/orange, black, or white color. In the matrix, a variety of ferromagnesium minerals, mainly iron oxide (hematite), biotite, and muscovite, was observed imparting a red stain to the surrounding fine fraction. Many of these minerals appeared to be very weathered, and the indistinct boundaries of some grains indicated alteration of these materials.

The aggregate, or coarse fraction, of these samples is chiefly quartz. Quartz grains, occurring in a wide range of particle sizes, comprise up to 60% of these stratigraphies. In almost every sample, the quartz grains are fractured in such a way that suggests they were mechanically crushed rather than weathered or naturally compromised. Plagioclase feldspar grains were also identified. Large inclusions were commonly observed in the thin sections. Most of these inclusions are calcareous blebs (calcite, dolomite), fossils, and the aforementioned ferromagnesium minerals. (See Appendix F for micromorphological descriptions.)

5.4.2 *Soluble Salts: Qualitative Analysis*

Theory

Soluble salts in earthen materials can be very destructive. These salts may be absorbed from groundwater through capillary action or accumulate as a result of burial. Salts can disrupt surfaces where they appear as efflorescence, or cause interior damage as subflorescence. While salt damage in porous building materials is widely recognized, the mechanisms of salt deterioration are not well understood. Some scientists postulate that the volumetric change resulting from salt crystallization and the formation of hydrated species, with an accompanying crystallization pressure, cause deterioration. Others argue that the cycles of wet/dry periods and hydration and dehydration of crystallizing salts stress porous materials. For whatever reason, soluble salts cause damage, and their hygroscopic nature attracts more water, an especially destructive influence on earthen materials. Additionally, the presence of soluble salts may skew the characterization of earthen materials if not accounted for, especially if the salts make up a significant part of the material's weight.[31]

A number of soluble salts appear frequently in architectural materials. These salts, identified by their respective anions, originate in a variety of ways. Sulfates, containing the ion $S0_4{}^{2-}$, most often appear as hydrous calcium sulfate (gypsum, $CaSO_4 \cdot 2H_2O$) and magnesium sulfate ($MgSO_4$). Sulfates may originate from agricultural land, sea water, materials used to prepare plaster and mortar, microbiological growth, and from atmospheric pollution. Chlorides (Cl^-), particularly sodium chloride ($NaCl$) and calcium

chloride (CaCl), originate from sea spray. Chlorides can also be present as impurities in mortar or plaster components (particularly sand), and as a result of some types of industrial activity. Nitrates (NO_3^-) and nitrites (NO_2^-) are often associated with organic material, and can be found in agricultural land and near burial sites and sources of sewage. Carbonate (CO_3^{2-}), manifest as calcium carbonate ($CaCO_3$), is a relatively insoluble salt that is most often deposited on wall surfaces when bicarbonate salts present in solution evaporate. Complex soluble alkaline salts other than sulfates, nitrates, and nitrites can be the result of leaching from repairs containing cement.[32]

Method

The identification of soluble salts was carried out using a recognized qualitative wet-chemical procedure.[33] A portion of Sample 15 weighing about 1 gram was ground to a powder using a mortar and pestle and placed in a beaker. Approximately 22 ml of deionized water was added to form a solution, which was gently agitated by swirling the beaker. The pH and conductivity of the solution was measured, as described below in 5.4.3. The solution was filtered using #5 filter paper in a funnel into another beaker, which was dried in a 90° C oven until the water evaporated. After the beaker cooled, 20 ml of deionized water was added to dissolve the salts remaining in the beaker. Approximately 2 ml of this solution was drawn off to each of four test tubes. Four test tubes with deionized water were prepared as controls.

To test for the presence of sulfates, 2 drops of hydrochloric acid (HCl) were

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[31] James R. Clifton, Paul Wencil Brown, and Carl R. Robbins, *Methods for Characterizing Adobe Building Materials*, National Bureau of Standards Technical Note 977 (Washington, D.C.: U.S. Department of Commerce, 1978), pp. 9-10.

[32] Jeanne Marie Teutonico, *A Laboratory Manual for Architectural Conservators, Exercise 16* (Rome: ICCROM, 1988), pp. 58-62.

added to the first test tube and the first control test tube, followed by 2 drops of barium chloride ($BaCl_2$). To test for chlorides, 2 drops of nitric acid (HNO_3) were added to the second test tube and its control, followed by 2 drops of silver nitrate ($AgNO_3$). To test for nitrites, 2 drops of acetic acid (HCH_3COO) were added to the third test tube and its control, followed by 2 drops of Greiss-Ilsovay's Reagent. To test for nitrates, a small amount of zinc powder was added to the same test tube and the control for test #3. To test for carbonates, 2 drops of HCl were added to the fourth test tube, a test tube containing the solids previously filtered out, and the control for test tube #4.

Results

The tests yielded negative results for sulfates and nitrites. Positive results were obtained for chlorides and nitrates, although not in abundant quantities. Strong positive results were obtained for the presence of carbonates in the water-insoluble solids of the sample.

5.4.3 *Conductance and pH*

Theory

Conductance is the measure of a solution's ability to carry electricity through the mobility of ions when subject to an electric current; in other words, the opposite of its resistance. While pure water is a nonconductor of electricity, the addition of certain compounds will allow the solution to conduct current; these compounds are called electrolytes. The conductivity of a solution depends on the concentration of the ions present, and the specific ions' mobility, size, and valence. Because salts are ionic

[33] Ibid. pp. 62-69.

compounds, measuring the conductance of the soil solution is a good way to determine the presence of soluble salts in earthen materials. Conductance measurements are best suited for strong electrolytes because the constituent ions are completely dissociated. Examples of strong electrolytes are sodium chloride, sodium sulfate, and gypsum. Conductance is expressed in the electrical unit microsiemens (μS), which is the SI unit for the microohm (μΩ).

The measurement of pH is always taken in an aqueous solution. An acid is a substance that yields hydrogen ions [H^+] when dissolved in water, while a base yields hydroxyl ions [OH^-]. Pure water (H_2O) always contains an equal amount of these ions (known as the ion-product constant for water, equaling 1×10^{-7} moles per liter of each ion) and is neutral. The product of the [H^+] and the [OH^-] will always be 1×10^{-14} moles per liter. The pH of a solution is expressed as the negative logarithm of the [H^+] concentration. Neutral solutions, like pure water, will have an equal concentration of [H^+] and [OH^-], and have a pH of 7. Since acidic solutions have more [H^+] than [OH^-], the [H^+] concentration will be more than 1×10^{0} moles per liter and less than 1×10^{-7} moles per liter; therefore its pH will be greater than or equal to 0 and less than 7. Similarly, basic (alkaline) solutions will have a pH greater than 7 and less than or equal to 14.[34]

The pH of an earthen material can indicate the presence of alkaline salts such as calcium carbonate, sulphates, nitrites and nitrates. More importantly, pH can help determine the stability of the clay fraction in the presence of water. As discussed in Chapter 4, some clays carry a negative charge. The abundance of positive hydrogen ions

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[34] Gershon J. Shugar and Jack T. Ballinger, *Chemical Technicians' Ready Reference Handbook, Fourth Edition* (New York: McGraw-Hill, 1996), pp. 657-658.

$[H^+]$, as in acidic solutions, promotes interlamellar swelling of these clays, where these positive ions are attracted. Organic compounds in soils create acidic conditions. While alkaline environments are more favorable for the stability of clays than acidic ones, the presence of salts, often indicated by a high pH, can lead to the flocculation of clay particles.

Method

The conductance of the soluble salts separated from earthen material from Sample 15 was measured with an Omega® pH/Conductivity Pocket Pal™ Meter. The salt solution prepared for the qualitative soluble salts analysis served as the subject for the measurement. The conductance electrode was rinsed with deionized water, then immersed in a sample of deionized water to confirm a conductance reading of 0 μS indicating that the meter was properly calibrated. The conductance electrode was then immersed in the salt solution three times to confirm the reading.

The pH of earthen material from Sample 15 was measured with the meter described above. The pH meter was calibrated with solutions of known pH. The subject of the pH measurement was the solution of the powdered sample and deionized water described in the analysis of soluble salts above. After the solution was agitated and before it was filtered and dried, the meter was used to measure the pH of the solution and the deionized water used to make the solution. The meter electrodes were inserted into the solution until a reading stabilized on the meter display. The same procedure was followed on the deionized water. The pH of the solution and the water was also measured using two different types of commercial paper pH indicator strips. These strips, which are impregnated with standard indicator chemicals, display colors that

depend on the pH of the solution being tested. The strips were immersed in the liquids and visually compared to color standards on the strip or on the strip container.

Results

The conductance reading for the soil solution was 660 μm, indicating an insignificant amount of electrolytes (presumed in this case to be salts). The pH meter gave a reading of 8.10 for the soil solution, and a reading of 5.50 for the deionized water. The indicator strips read 7.0 and 7.5 for the soil solution and 6.9 and 7.5 for the deionized water. The pH meter readings can be interpreted as being less reliable, even though the apparatus had just been calibrated. The meter had been giving erratic readings indicative of a failing electrode, so the values given by the pH strips were accepted, particularly because they were relatively consistent with each other. The neutral pH of the soil implies a relatively stable environment for the clay fraction.

5.4.4 *X-ray Diffraction*

Theory

X-ray Diffraction (XRD) is an instrumental analysis that is useful for the identification of crystalline materials. Nearly all minerals have crystalline structure, so XRD is a useful tool for identifying and quantifying components of earthen architectural materials. The wavelengths of X-rays are in the same order as the distances between atoms in crystalline materials, and the spacings in a crystalline structure can act as diffraction gratings for X-rays. For a bulk sample, the material is ground to a powder and mounted in a diffractometer. The sample is bombarded with X-rays, which strike electrons close to the nuclei of atoms in the sample and knock these electrons out of their

orbitals. Electrons from outer orbitals drop immediately into these vacancies, resulting in a drop in energy that appears in the form of an X-ray photon with a given frequency; this photon is read by a detector. Every element has a characteristic energy difference between orbitals as a function of the number of protons in the nucleus.[35]

The sample is bombarded with X-rays from a range of angles, referred to as the 2θ angles, at a rate of a given number of degrees per minute (for most architectural materials, 2θ = 2° to 60°, at 1° per minute). The 2θ angle is varied in order to diffract the X-rays from the X-ray source through all of the interplanar spacings of the atoms in the sample. A spectrum is produced for the sample where 2θ is plotted against the intensity of the photons detected. This spectrum is compared to a database of spectra to determine the elemental composition of the sample. Powder XRD can identify materials that make up 10% or more of the bulk sample.

Method

Two samples were submitted for XRD analysis: a collection of the finishes garnered from the 23 Kiva Q samples, and a sample of prehistoric mortar from section 4A of Kiva Q. Both samples weighed a total of about 20 grams each, which is the minimum amount recommended for analysis of the clay-sized fraction. The bulk mineralogy of the samples was determined by mounting an unoriented powdered sample on a sticky glass slide, and analyzed using a Rigaku D-Max 2 diffractometer and a copper tube with a monochrometer. Powder XRD is relatively simple and yields moderately quick results, but the interpretation of spectra takes practice and experience. XRD analysis of clay minerals is more complex, requiring extensive sample preparation and

[35] Moore and Reynolds, pp. 28-33.

high temperature heating. Persons proficient in the interpretation of XRD data should perform Quantitative XRD of clays in properly equipped laboratories. Dr. George Austin of the New Mexico Bureau of Mines and Mineral Resources performed both the bulk mineral analysis and the quantitative analysis of clay-size material in a sample of a mortar and finishes from Kiva Q. In the quantitative analysis of clays in this sample, the clay-size fraction (< 2μm) was separated from the bulk sample by sedimentation, placed on a glass slide, then dried. The slide was examined with X-ray diffraction from 2° to 35° 2θ, soaked in an ethylene glycol atmosphere and examined again from 2° to 15° then 8.5° to 9.5° 2θ. The slide was then heated to 350° C for 30 minutes, and examined from 2° to 15° 2θ. The glycolization and heating procedures make active clays such as smectite and illite expand, altering the resulting intensity of the XRD spectrum peaks. This method quantifies the clays present in the < 2μm fraction of a sample in parts of ten, and identifies the following clay mineral groups: kaolinite, illite, smectite, chlorite, and I/S (mixed layer illite-smectite). See Appendix H for X-ray Diffractograms.

Results

<u>Kiva Q Plaster</u>

Bulk Mineralogy—from most abundant to least: quartz, calcite, plagioclase feldspar, clay (?)

Clay-Size Mineralogy: Illite/Smectite mixed layer 4 parts in 10
Kaolinite 3 parts in 10
Illite 2 parts in 10
Smectite 1 part in 10
Also calcite, and some unknown

Kiva Q Mortar

Bulk Mineralogy—from most abundant to least: quartz, plagioclase feldspar, kaolinite, illite/smectite mixed layer, some unknown

Clay-Size Mineralogy: NO CLAY MINERALS
Nitratine ($NaNO_3$)*
Rosickyte (sulfur)*

*These two compounds indicate the presence of gunpowder. Gunpowder blasting has been associated with looting activities of pot hunters in the late nineteenth century, who used dynamite to provide openings in the masonry for light and air during digging.

5.4.5 *Scanning Electron Microscopy with Energy Dispersive X-ray Microanalysis*

Theory

A Scanning Electron Microscope (SEM) is a kind of reflecting microscope that uses electrons instead of light photons to illuminate an object. A heated filament emits electrons that are driven by a high voltage (10-50 kV) through a series of electromagnetic lenses that focus the electrons to a beam approximately 2 nanometers in diameter. The beam passes through a final electromagnetic lens containing coils that drive the beam in an x-y scanning raster. The interaction of the beam with the sample produces secondary, low-energy electrons. A visible signal is generated on a cathode ray tube, which traces the scanning raster and creates variable levels of visual contrast depending on the number of secondary electrons collected at each point on the sample. This image may also be recorded on film or videotape, or stored in a computer.[36] This system operates in a high vacuum. Materials that are to be examined with SEM need to be conductive in order to dissipate the electrons from the beam, so samples are often coated with carbon or gold to

make them conductive. Samples to be examined with EDS should not be coated with gold, which will interfere with the detection of X-ray photons.

An Energy-Dispersive X-ray Analyzer (EDS) is simply an X-ray detector used in conjunction with a SEM. When a sample is analyzed with the SEM beam, characteristic X-rays are emitted. These x-rays may be analyzed with a wavelength dispersive system (WDS), which measures the wavelength of emitted X-rays by passing them through appropriate analyzing crystals, or with an EDS, which measures the energies of emitted X-rays through a multi-channel analyzer. WDS is very accurate and is used mainly for quantitative analysis, while EDS immediately provides the complete spectrum that is more useful in qualitative analysis.[37] EDS, providing elemental composition of a sample, can be used simultaneously with SEM to generate visual maps of the location of each element within a sample.

Method

Analysis was facilitated by Rollin Lakis and Douglas Yates at the Laboratory for Research on the Structure of Matter at the University of Pennsylvania. Two samples from Kiva Q, Sample 6 and Sample 11, were analyzed with SEM/EDS on a JEOL JSM 6400 Scanning Microscope at 30x magnification at 15kV. The author prepared the samples by first consolidating them with 5% w/v Acryloid B-72 Ethyl Methacrylate in acetone. The samples were then embedded in BioPlast™ and sectioned with a Buehler Isomet™ low speed saw to reveal the cross sections.

The cross sections were mounted on an aluminum sample stub with carbon paint, and coated with carbon in a high vacuum coating apparatus before being examined in the

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[36] Dr. A. Elena Charola, lecture notes, University of Pennsylvania, 1999.

SEM. An X-ray spectrum was generated for the Sample 11, which determined the elements to be mapped for both samples (See Appendix I for spectrum). The samples were scanned at x and y resolution of 512 at process time 2, at a rate of 2 milliseconds per pixel with 20% dead time. Each sample required about 3 hours of scanning time. (See Appendix I for Electron Digital Maps.)

Results

The main elemental peaks that were identified by the preliminary X-ray spectrum are aluminum (Al), calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), silicon (Si), sulfur (S), and Titanium (Ti). A map was generated for each identified peak in both samples. The second map for aluminum, named Al2, may result from a technical error in labeling during the mapping process and could represent the Si peak. Additional maps were generated for the background image (BEI), and a backscatter energy image (BK) for each sample.

Aluminum- Both Al1 and Al2 show an abundance of aluminum in both samples, probably from the presence of aluminosilicates as clays and silts. If Al2 is actually the Si map, the bright indicators on the maps would correspond to the quartz grains.

Calcium- Discreet bright spots on the calcium map represent calcareous inclusions in both samples. Bright lines in the maps indicate pigment layers composed of calcareous minerals.

Copper- Low-level spotting in the copper maps suggest the presence of an ubiquitous copper-bearing mineral in the soil.

Iron- Bright spots in the iron maps represent ferromagnesium inclusions,

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[37] Ibid.

especially hematite. Iron minerals in the soil show are manifested as small, dim spots throughout the maps.

Potassium- Bright spots in the potassium maps indicate inclusions of minerals such as feldspars and micas, while dim spots represent clay and silt minerals such as illites.

Magnesium- Most of the spots on the magnesium map for Sample 11 are low-level indicators of ferromagnesium clays and feldspars. In Sample 6, bright spots on the magnesium map correspond to many bright spots on the calcium map, possibly indicating inclusions of dolomite ($Ca\,Mg(CO_3)_2$).

Sulfur- In Sample 6, a bright line in the sulfur map corresponds to a line in the calcium map; this identifies the pigment in the corresponding layer as gypsum ($Ca\,SO_4 \cdot 2H_20$), a compound used as a white pigment. This result is puzzling, because there were no white layers observed in Sample 6. The spots on the Sample 11sulfur map are less distinct, suggesting that gypsum is naturally present in the soil, a finish component, or possibly a result of groundwater contamination.

Titanium- In both sample maps, titanium spots are discreet but relatively nonabundant, and possibly indicate titanium-bearing silicates such as titanite ($CaTiO(SiO_4)$).

5.4.6 *Fourier Transfer Infrared Spectroscopy*

Theory

Spectroscopy is the study of the interaction of electromagnetic (EM) radiation with matter. EM radiation is a continuous energy transmitted by electromagnetic waves.

which consist of alternating electric and magnetic fields. Spectroscopy is used to measure and interpret EM radiation absorbed, scattered, or emitted by atoms, molecules or other chemical species. Spectroscopy utilizes the energy of the electromagnetic spectrum, a broad, continuous range of energy, wavelength, and frequency. In the EM spectrum, radiations with shorter wavelengths (gamma rays, x-rays) have more energy than radiation with longer wavelengths (microwaves, radio waves). High-energy radiation like X-rays can cause electronic changes in atoms, while lower energy infrared waves produce changes in the translational, rotational, and vibrational energies of a molecule. XRD and SEM are examples of emission spectroscopy, where radiation is applied to a sample that becomes excited and emits energy as it returns to its ground state. Infrared (IR) spectroscopy is an example of absorption spectroscopy, where part of the radiation applied to a sample is selectively absorbed. IR measures the portion of energy that is not absorbed to identify the sample.[38]

In a Fourier Transform Infrared Spectrophotometer, an EM radiation source is directed through a number of mirrors and focusing beamsplitters before the beam is applied to the sample. The sample selectively absorbs portions of the IR radiation causing vibrations of the molecules' atoms and functional groups. The decrease in the energy of the beam resulting from the sample absorbing IR radiation can be used to quantify the amount of sample present. A detector measures and converts the unabsorbed portion of the beam's energy to an electric signal that is interpreted by a computer and recorded as an IR spectrum. An IR spectrum is a plot of absorption bands that correspond to characteristic vibrational frequencies of functional groups (amines,

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[38] Dr. Beth Price, lecture notes, Philadelphia Museum of Art, 1999.

ketones, alcohols, etc.) and of the molecule as a whole.[39] The spectrum produced by analysis is compared to a database of spectra to identify the sample. While data acquisition with IR analysis is very quick, interpretation can be very time consuming.

Method

Analysis was carried out by Dr. Elizabeth Price at the Analytical Laboratory of the Philadelphia Museum of Art. Material from Sample 15 and Sample 10 was analyzed using a Nic-Plan™ IR Microscope attached to a Nicolet™ 510P FT-IR Spectrometer. Samples were prepared by extracting a small amount of material under a low-powered microscope, mounting the material on a diamond window, and flattening it with a roller tool. Each sample was examined by placing the diamond window with the sample on the microscope stage, and focusing the microscope away from the sample to collect the background spectrum. After focusing the microscope on the sample, the sample spectrum was collected and printed. The sample spectrum was then compared to spectra obtained from a search of digitized libraries.

Results

Two materials from Sample 15 were examined: samples were extracted from a white finish (referred to in the spectra as the upper white layer), and from the reddish tan base coat of plaster (referred to as the red lower layer). See Appendix J for spectra. The Sample 15 red lower layer spectrum matched a montmorillonite (smectite) database spectrum. Comparison of database spectra to the upper white layer spectrum indicated the presence of gypsum and a small amount of kaolin that was confirmed with a 2nd Derivative analysis. The small quartz peak in the white layer spectrum was a further

[39] Ibid. and Dr. A. Elena Charola, lecture notes, University of Pennsylvania, 1999.

indication of kaolin, which has a characteristic quartz peak in database spectra.

Two materials from Sample 10 were analyzed: a white finish and a black finish. The white layer spectra peaks matched those of gypsum and approximated those of sodium oxalate ($NaC_2O_4 \cdot H_2O$). The latter white layer peaks suggest the presence of calcium oxalate, a weathering product associated with microbiological growth, also known as the organic mineral whewellite. No database spectra for calcium oxalate were available. Spectra for the black layer indicate the presence of gypsum, a small amount of kaolin, and the speculative calcium oxalate.

5.5 SUMMARY OF DATA RESULTS

The walls of Kiva Q are covered with a complex system of earthen finishes, ranging from thick leveling coats of plaster to micro-thin clay washes and soot layers. The plasters are comprised of a high percentage (up to 60%) of quartz grains of various sizes and colors in a relatively homogeneous reddish-brown matrix. This matrix is comprised of a combination of clays identified by XRD, including illite/smectite mixed layer, kaolinite, illite, and smectite, as well as larger particle ferromagnesium minerals (plagioclase feldspar, micas, and hematite), and calcite. The plaster aggregate consists of quartz sand grains that have been crushed, and inclusions of calcareous materials and ferromagnesium particles identified by thin section microscopy, XRD, and SEM/EDS.

Washes were applied to the kiva in a deliberate fashion to define space by creating artificial hierarchies among and within different architectural elements. These hierarchies were expressed in colors imparted by the washes. The washes contain little or

no sand grains and a high percentage of pigments, derived from inorganic and organic sources to create black, white, brown and red color fields and discreet designs. Pigments identified by visual analysis, microchemical spot testing, and instrumental methods include gypsum and kaolinite (white), iron oxide (red), and organic carbon compounds (black). Chemical tests indicated a relatively favorable environment of neutral pH and low salinity for the preservation of the clays in the finishes.

Chapter 6

CONCLUSIONS

The samples of earthen finishes collected from Kiva Q provided a valuable representative window through which to help interpret physical and visual characteristics of the material and the architecture over which it was placed. In the interests of minimal destruction of the cultural resource, the 23 samples removed from Kiva Q were as small as possible, many weighing less than 2 grams. Due to the small sample size, geotechnical tests to determine grain size distribution and physical properties of the soil such as liquid and plastic limits could not be implemented. The examination of thin sections was hampered by loss of the fragile material during section preparation. Still, the samples yield a large amount of information through visual and instrumental analysis.

6.1 PLASTER

Plaster layers in Kiva Q tend to be relatively thick and contain 50-60% aggregate, which consists almost entirely of multi-colored quartz grains in a range of sizes. The quartz grains in many of the samples are fractured from mechanical crushing, suggesting that the Ancient Puebloan plasterers manipulated the aggregate. The plaster matrix is a soil containing a variety of clay types, calcite, feldspars, micas, and hematite (iron oxide). The plasters are varying shades of reddish brown, and owe their color to the aggregate and the soil, particularly iron oxide that may have been obtained from mesa-top soil containing wind-blown red loess.

Plaster was applied to Kiva Q as the first layer over the masonry substrate, and acted as a leveling coat. A second plaster coat was applied over the first. Other layers of plaster occur sporadically throughout the kiva, presumably to repair or level areas of significant finish loss, or to create large color zones.

6.2 WASHES

Washes in Kiva Q tend to contain very little aggregate and consist mainly of silt and clay particles, mixed with mineral pigments ground into the soil matrix to impart color. Instrumental analyses suggest that the white washes comprise of gypsum, although other white pigments such as calcium carbonate and kaolinite could have been used in place of or in conjunction with gypsum. Gypsum was also detected where it was not anticipated, in a black layer (in Sample 10, with FTIR) and where no distinct white layer was visible (in Sample 6, with SEM/EDS). In the case of Sample 10, the presence of gypsum might be attributable to soluble salt contamination or a vestige of the underlying white layer. In Sample 6 gypsum may comprise a large percentage of an indistinct layer that is perceived as a color other than white, such as a tan, buff, or pink wash. The red pigment, while not detected by instrumental analyses, was identified by microchemical tests as iron oxide. Most of the wash layers are very thin, ranging in thickness from 0.03mm to 0.8 mm. Still, the washes are relatively opaque as seen on the kiva walls, testifying to the visual strength of the pigments and the earthy binder.

Washes were used to create a number of visual effects in Kiva Q through the use of color (See Appendix E). Large color fields were applied to the banquette as

backgrounds or dados, and to pilasters to create contrasting effects. Continuous features such as wall and floor bands were applied to the banquettes. Washes were also applied as discreet designs, rendered as geometric images or handprints.

6.4 SOOT LAYERS

Large areas in Kiva Q are covered with a black substance. This substance, unlike plasters and washes elsewhere in the kiva, exhibits none of the characteristic surface textures of having been applied, such as striations or burnishing from application or finishing tools. This material, appearing as black layers occurring repeatedly throughout some stratigraphies, is understood to be soot deposited by hearth fires in the kiva. Soot is defined as "a black carbonaceous substance or deposit consisting of fine particles formed by the combustion of coal, wood, oil, or other fuel."[40] While no carbon was detected by instrumental analyses, transmitted light microscopical examination of materials in black layers extracted from cross sections reveals very fine, homogeneous, opaque particles. If the black layers were applied washes having charcoal, mineral or soot pigments, the layers would appear more heterogeneous, and possibly contain larger particles of wood or grains of quartz aggregate. It is likely that the black substance on the kiva walls are layers of soot resulting from the combustion of wood or other organic fuel available to the inhabitants. It is not known whether the soot was accumulated over a long period of time or deposited in one deliberate action.

Evidence provided by visual examination of the site and of the stratigraphies

[40] *Oxford English Dictionary*, http://oed.library.upenn.edu/oedbin/oed-def?query=soot&submit=Search, April 1, 1999.

indicates that distinct black layers occur only above the banquette, on the upper walls and pilasters. The concentration of soot on the upper part of the kiva could be a result of preferential deposition of soot particles suspended close to the roof by the hot air of the fire. Whatever the reason and mechanism for the soot deposition, the resulting black color fields were utilized to create visual effects within the kiva. The soot deposits on the upper walls and pilasters were left untouched or partially or totally covered depending on the visual scheme desired.

6.5 TEMPORAL DESIGN SCHEMES

On-site observations of Kiva Q and visual examination of stratigraphies indicate several design campaigns represented within the surface finishes of the kiva. Applied washes and plasters were combined with soot deposits to create different visual effects on the kiva surfaces. Observations of finish layers in situ hint at a bichrome dado treatment of the banquette. This speculative dado, a red field on the lower half of the banquette next to a white upper field, could have featured a motif of a series of three triangles similar to the dado observed in Room 121 in Cliff Palace. Stratigraphies suggest a red and white horizontal bichrome treatment on the pilasters echoing the tan and black appearance of the pilasters as they appear today.

Vestiges of continuous designs, wall bands of red triangles and white triangles, and a buff-colored floor band, can be seen on the kiva. Discreet designs appearing on the most recent finish layer include a pair of handprints on Pilaster 3 and an ambiguous semi-transparent red inverted V shape near Niche 4. The vertical hemispherical division of the

banquette expressed in the uppermost finish layer seems to be unique, as the other design schemes inferred by observation and stratigraphies appear consistently over the kiva surface.

6.6 RECOMMENDATIONS FOR FURTHER RESEARCH

An understanding of the material composition of the finishes used in Kiva Q and elsewhere in Cliff Palace would be enhanced by soil surveys and studies conducted in the vicinity to determine the sources for the earthen finishes. The connection between the material and architectural products of the Ancient Puebloans, specifically pottery and architectural surface finishes, should be explored to shed light on the similarities of these artifacts. A correlating study of ceramics made by the ancient inhabitants of Mesa Verde should be tied in to further research on the physical properties of these durable plasters and washes. Further analysis of the pigments used in these finishes should be implemented to gain a better understanding of the range of inorganic and organic colorants used by the Ancient Puebloans.

The questions raised by the enigmatic dividing line visible in Kiva Q still have not been definitively answered. Comparative investigations within and outside the kiva should be undertaken by collecting more samples. Proving or disproving the speculation that the kiva was divided into two sections in more than one finish campaign is hampered by the destruction of the west wall, but taking a more representative array of samples from the southern region of the kiva would go far in resolving this issue. The hypothesized cultural division of Cliff Palace, which might be represented by the visual

division of Kiva Q, can be investigated by comparing the surface finishes of Kiva Q to those of structures surrounding the kiva and of structures (including kivas) elsewhere in Cliff Palace, especially on the south side of the dividing wall feature observed by Dr. Nordby.

The material characterization of earthen architectural finishes is more than an exercise in classification or documentation. These materials are identified and described for the purpose of conserving the fragile finishes made from them. To that end, research on materials characterization should be incorporated into the development of compatible consolidants and adhesives to slow the deterioration of earthen finishes. Conservation treatments, coupled with other protective measures (e.g., documentation, monitoring, environmental mitigation) should be implemented to encourage the continued existence of these ephemeral resources.

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ILLUSTRATIONS

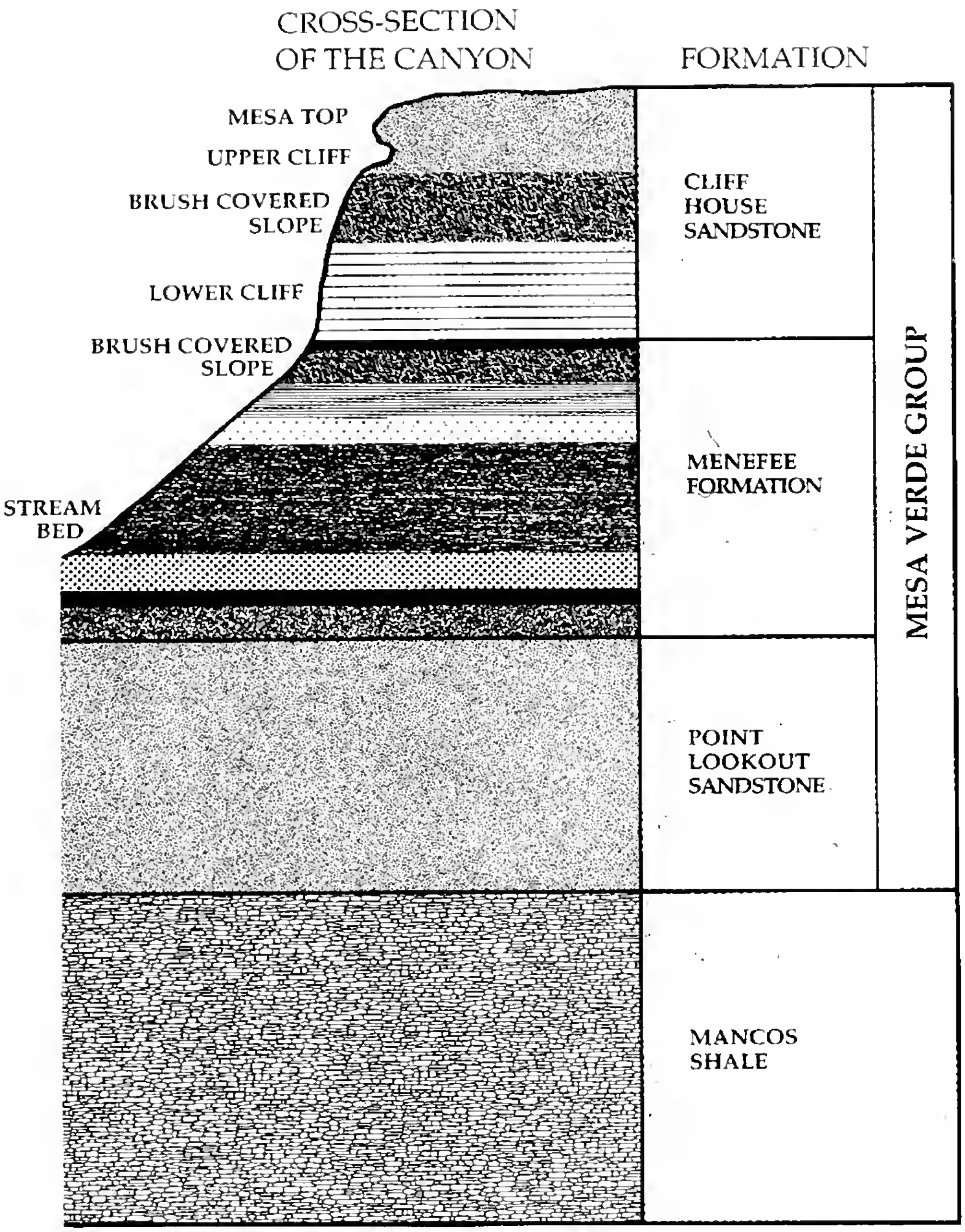


Figure 1. Mesa Verde geology. From Gilbert R. Wenger, *The Story of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1997), p. 10.

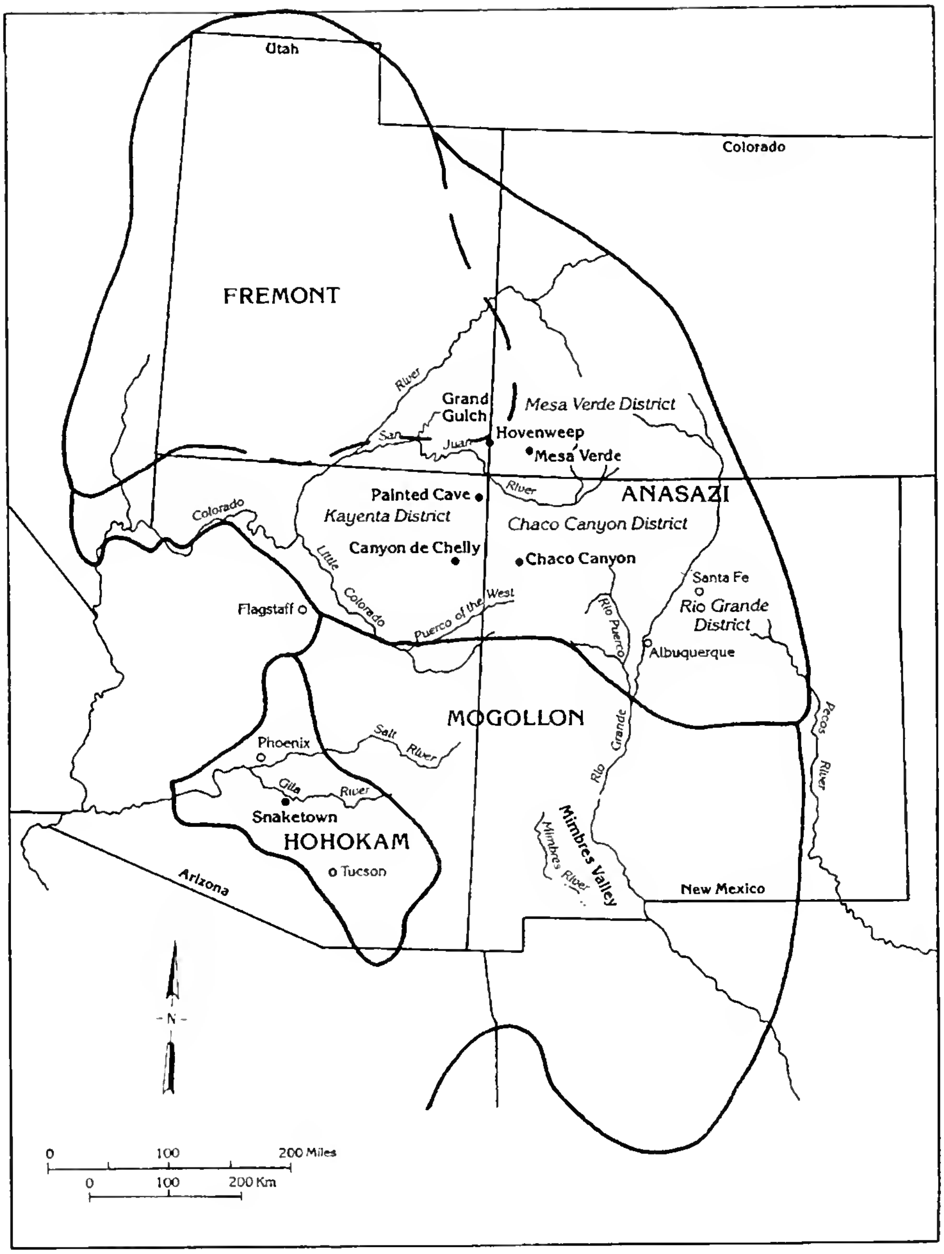


Figure 2. The Four Corners Area, with significant prehistoric cultural groups. From J.J. Brody, *Anasazi and Pueblo Painting* (Albuquerque: University of New Mexico Press), p. 26.

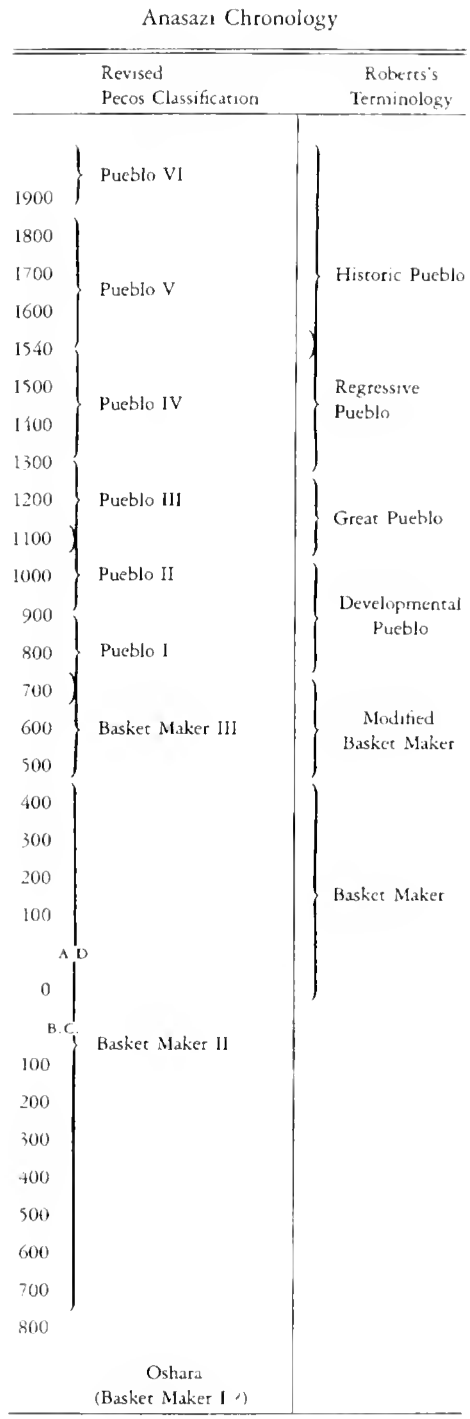


Figure 3. Cultural chronologies of the Puebloans. From William M. Ferguson and Arthur H. Rohn, *Anasazi Ruins of the Southwest in Color* (Albuquerque: University of New Mexico Press, 1987), p. 6.

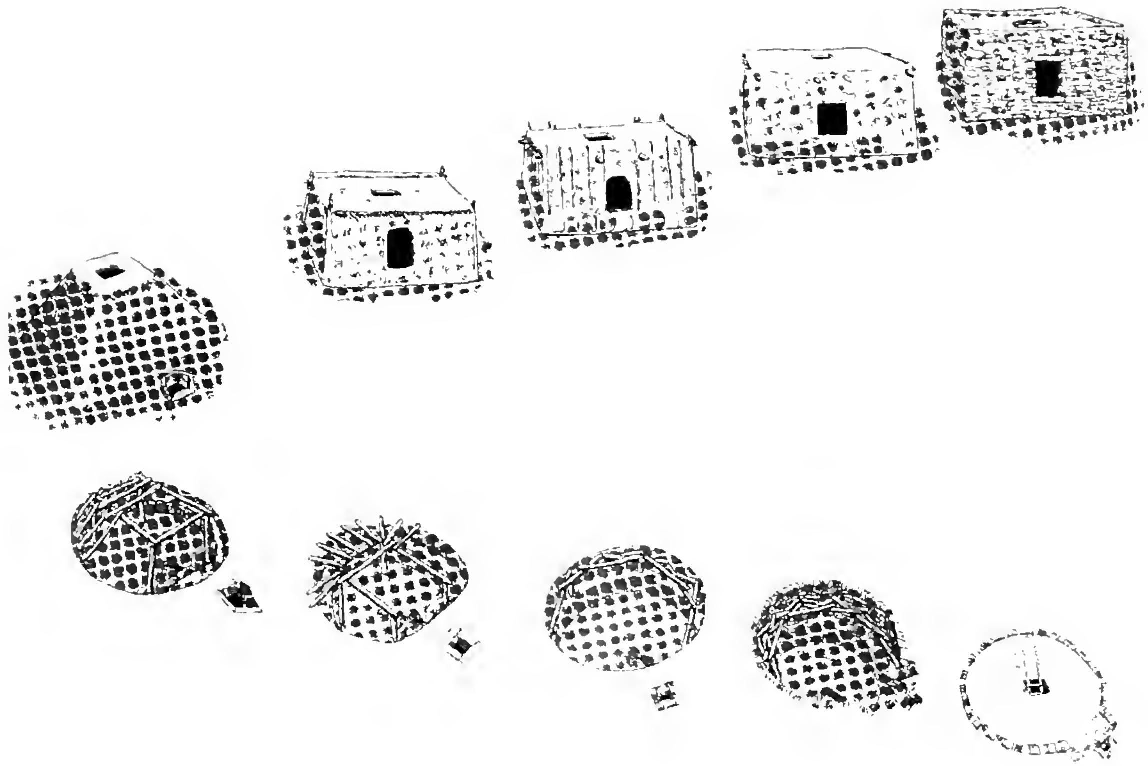


Figure 4. Development of the Ancient Puebloan pithouse to the pueblo and the kiva. From Gilbert R. Wenger, *The Story of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1997), p. 40.

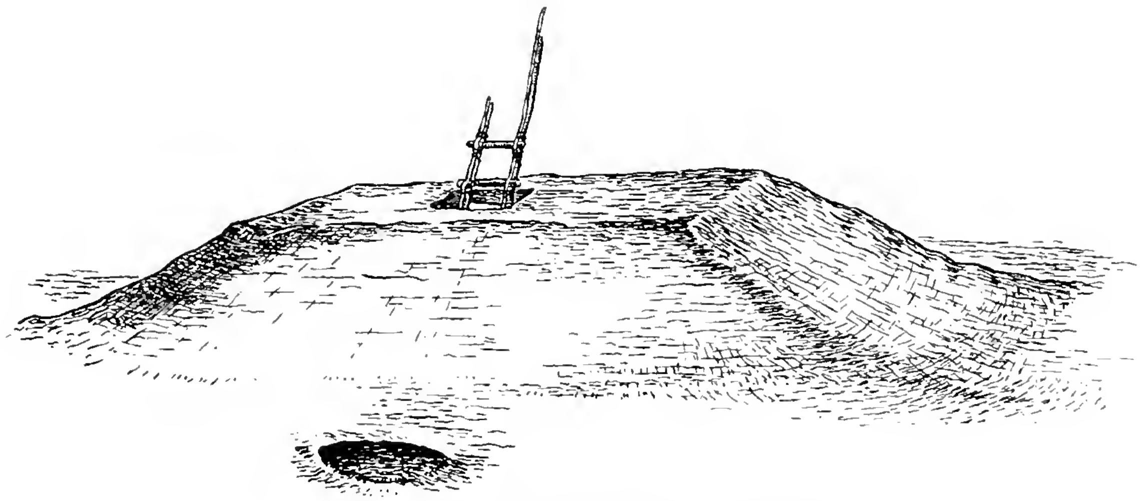


PLATE 5—*Postulated Method of Roof Construction of First Pithouse*

A. Main support posts.
B. Main stringers.
C. Secondary stringers.
D. Slender poles or withes.
E. Sloping side poles.
F. Poles, brush, or reeds.
G. Bark and trash fill.
H. Earth covering.
I. Tunnel to antechamber.
J. Deflector.
K. Wingwall
L. Firepit
M. Sipapu.
N. Plastered walls.
O. Bench.
P. Smokehole and hatchway.

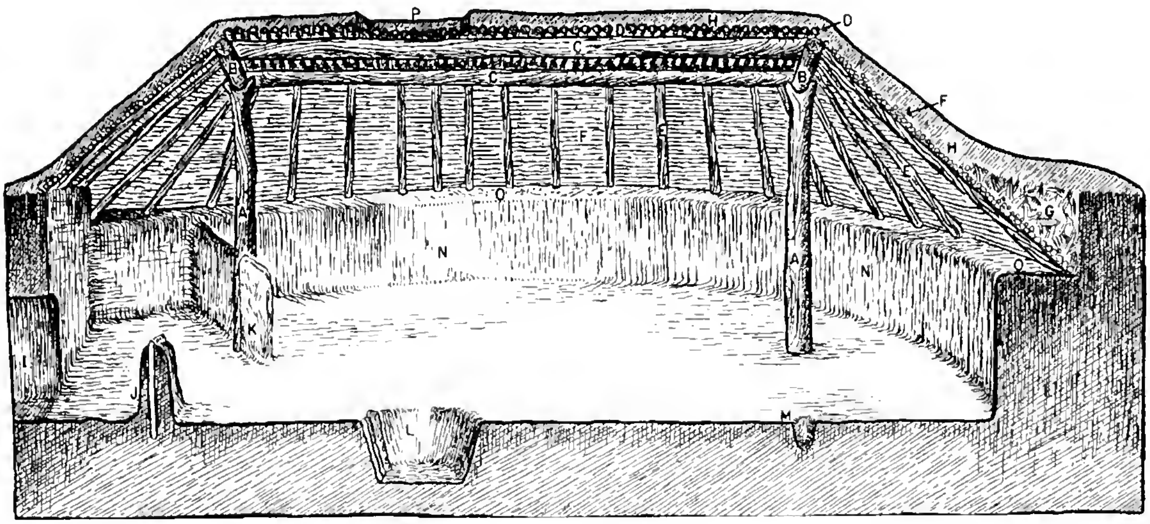


Figure 5. Schematic of Late Modified Basket Maker pithouse. From James A. Lancaster, et al., *Archaeological Excavations in Mesa Verde National Park, Colorado, 1950* (Washington, D.C.: National Park Service, 1954), p. 13.

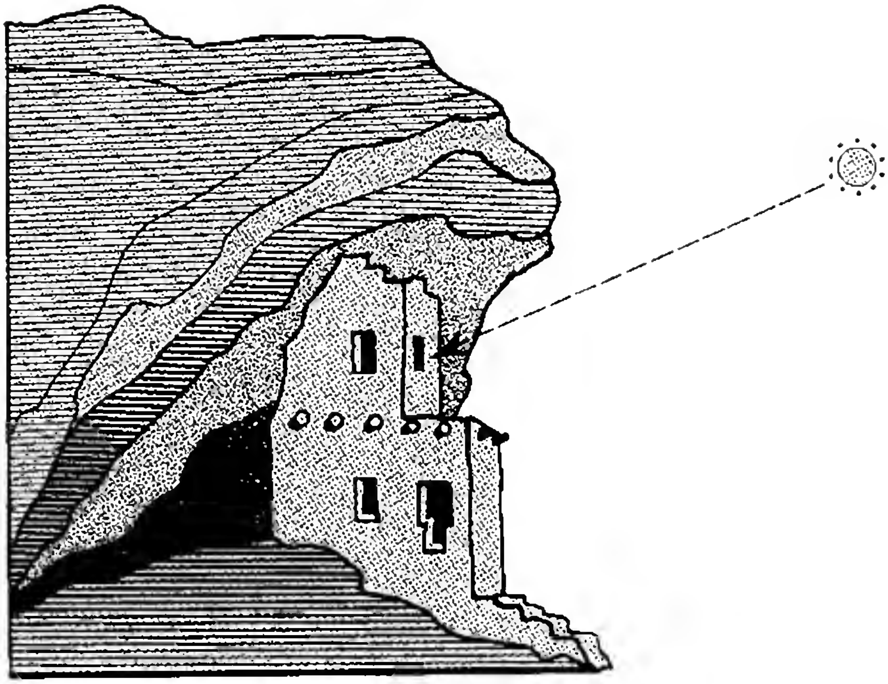


Figure 6. Schematic of Classic Pueblo alcove cliff dwelling. From Gilbert R. Wenger, *The Story of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1997), p. 17.

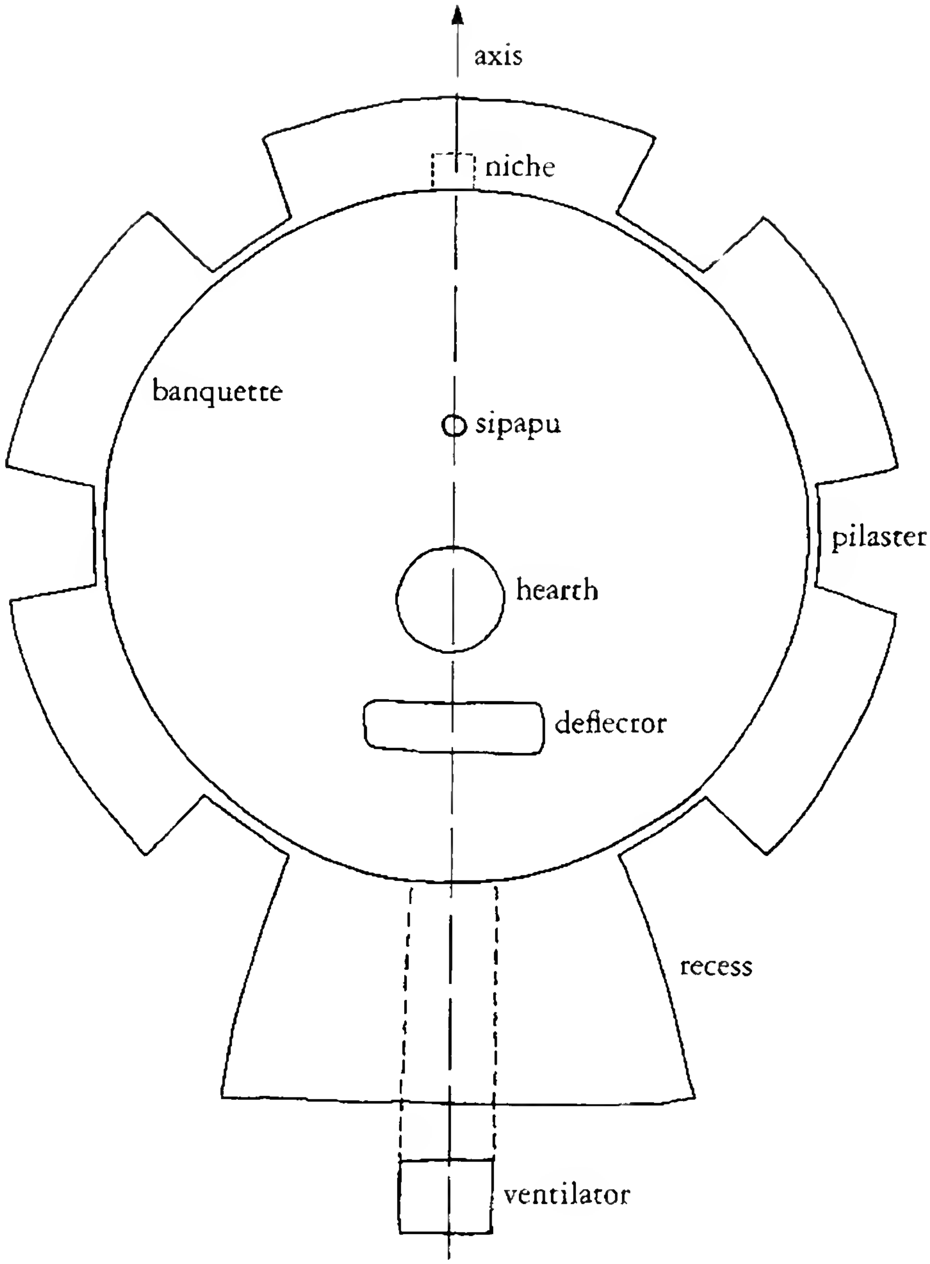


Figure 7. Typical Mesa Verde kiva plan. From William M. Ferguson and Arthur H. Rohn, *Anasazi Ruins of the Southwest in Color* (Albuquerque: University of New Mexico Press, 1987), p. 29.

Figure 8. Cliff Palace, 1894. Photo by Gustav Nordenskiold.

Figure 9. Cliff Palace, present time. From Gilbert R. Wenger, *The Story of Mesa Verde National Park* (Mesa Verde National Park, CO: Mesa Verde Museum Association, 1997), p. 51.

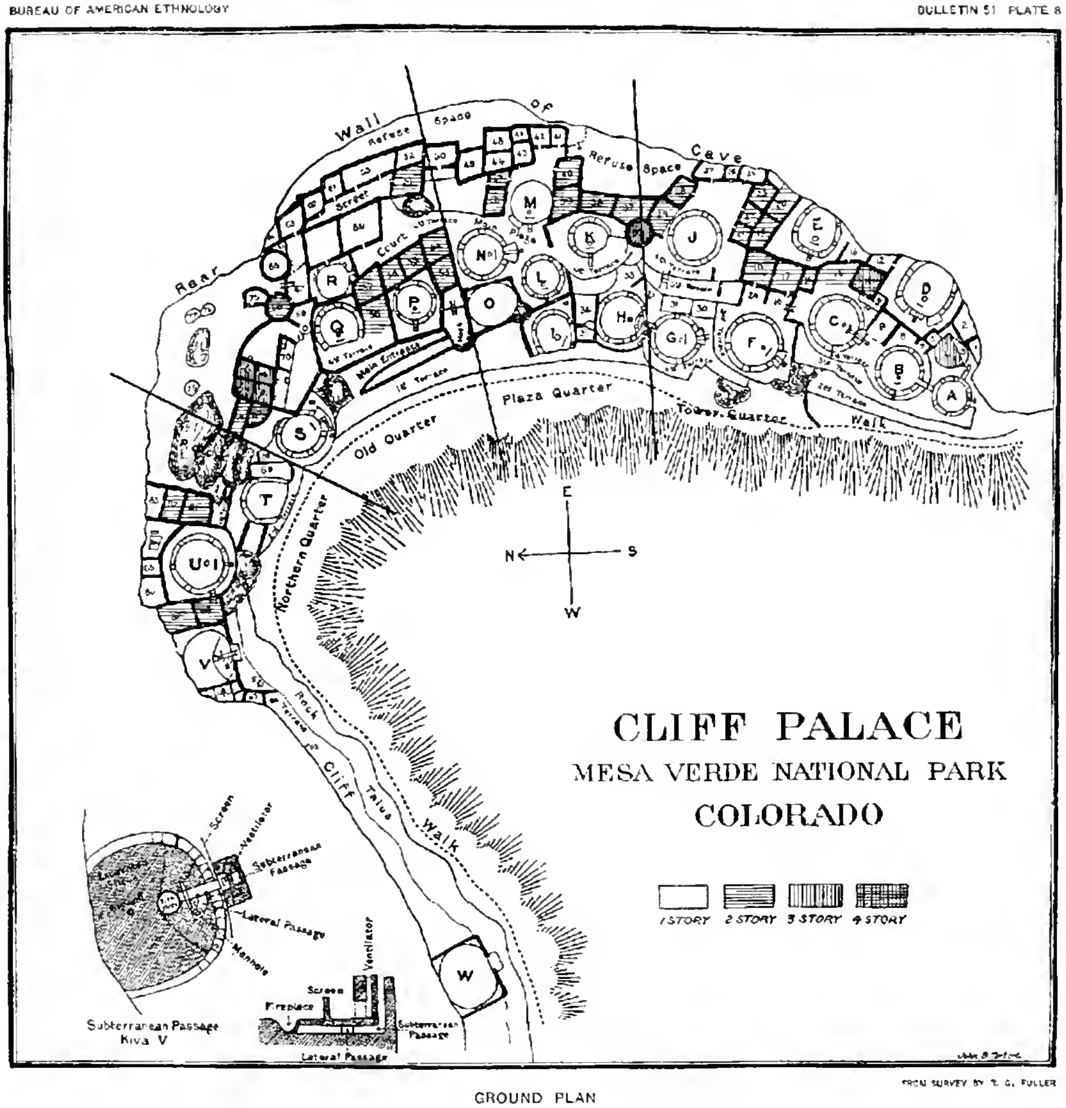


Figure 10. Plan of Cliff Palace. From Jesse Walter Fewkes, *Antiquities of the Mesa Verde National Park: Cliff Palace*, Smithsonian Institution Bureau of American Ethnology Bulletin 51 (Washington, D.C.: Government Printing Office, 1911) Plate 8.

Figure 11. Jesse Walter Fewkes in Kiva Q. (Nusbaum catalog No. 9523 #19)

Figure 12. Kiva Q, north wall, deflector.

Figure 13. Kiva Q, east wall, deflector.

Figure 14. Kiva Q, south wall.

Figure 15. Kiva Q, dividing line in the uppermost finish layer.

Figure 16. Kiva Q, Pilaster 3 with hand print designs

Figure 17. Kiva Q, Pilaster 4

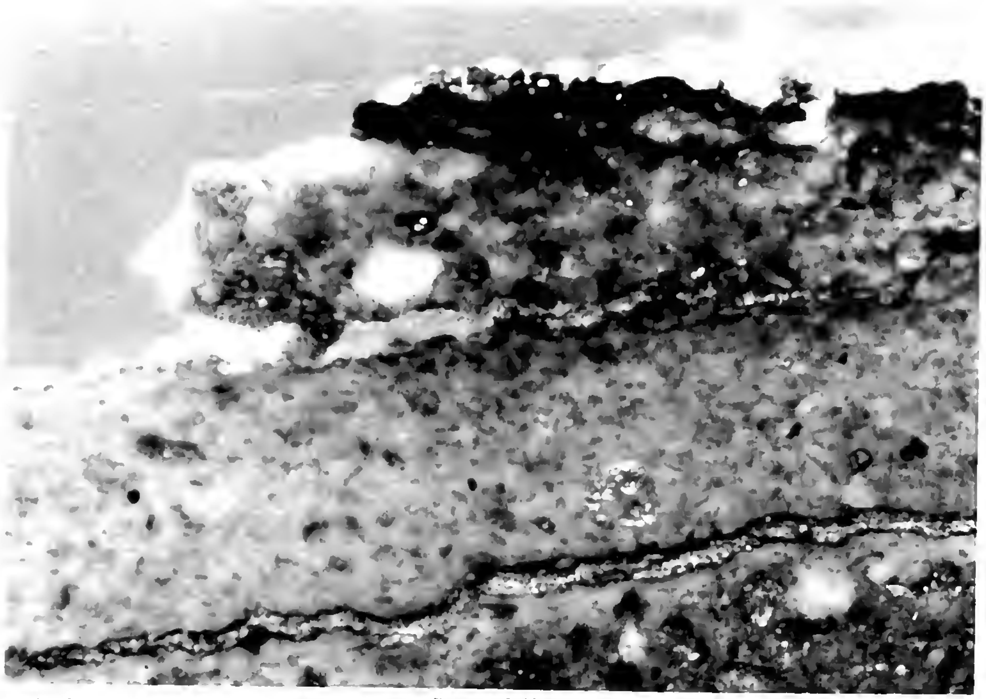


Figure 18. Sample 6 cross section. Reflected light, 10x magnification.

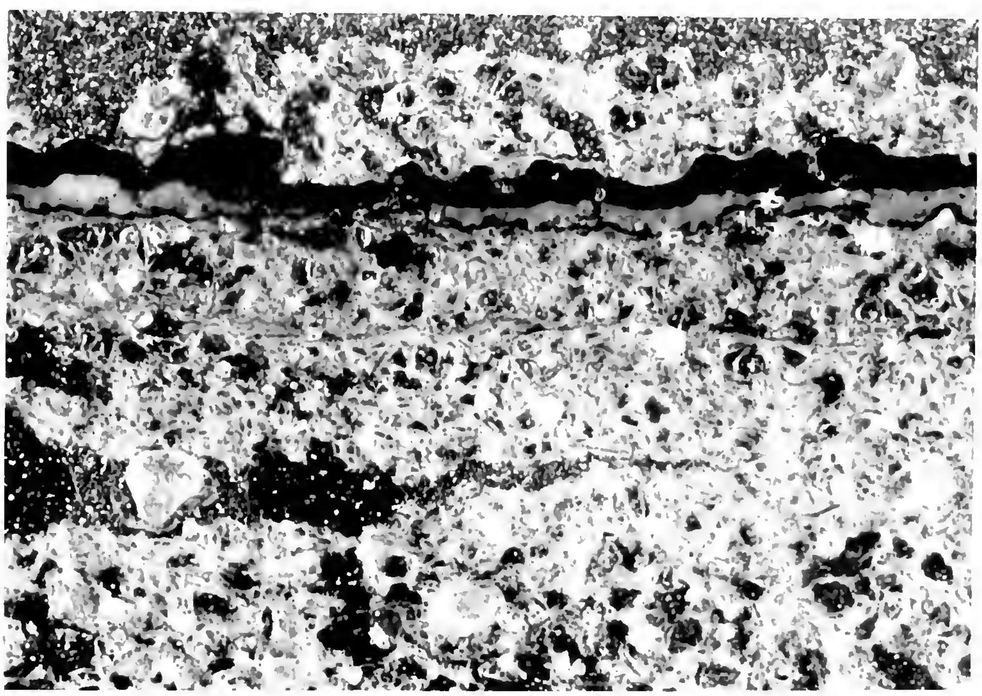


Figure 19. Sample 6 thin section. Pseudo-darkfield reflected light, 10x magnification.

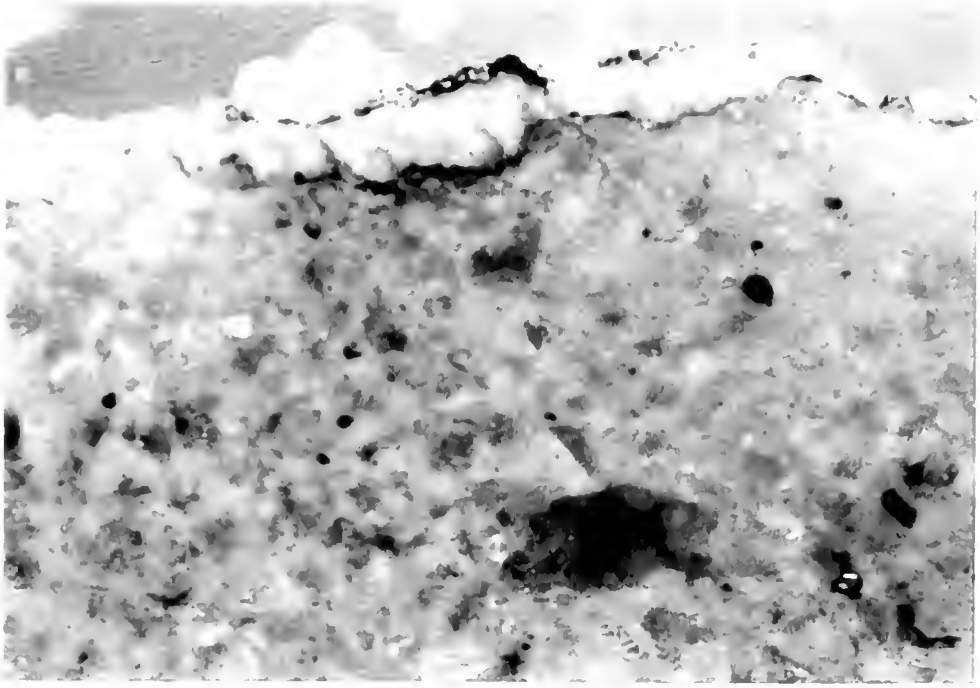


Figure 20. Sample 10 cross section. Reflected light, 10x magnification.

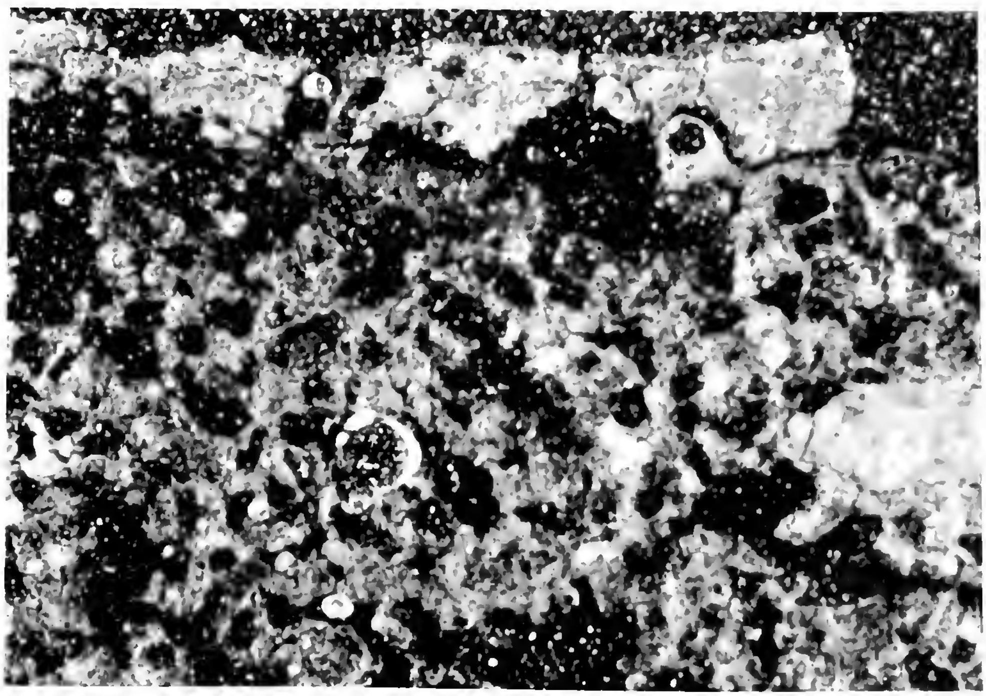


Figure 21. Sample 10 thin section. Pseudo-darkfield reflected light, 10x magnification.

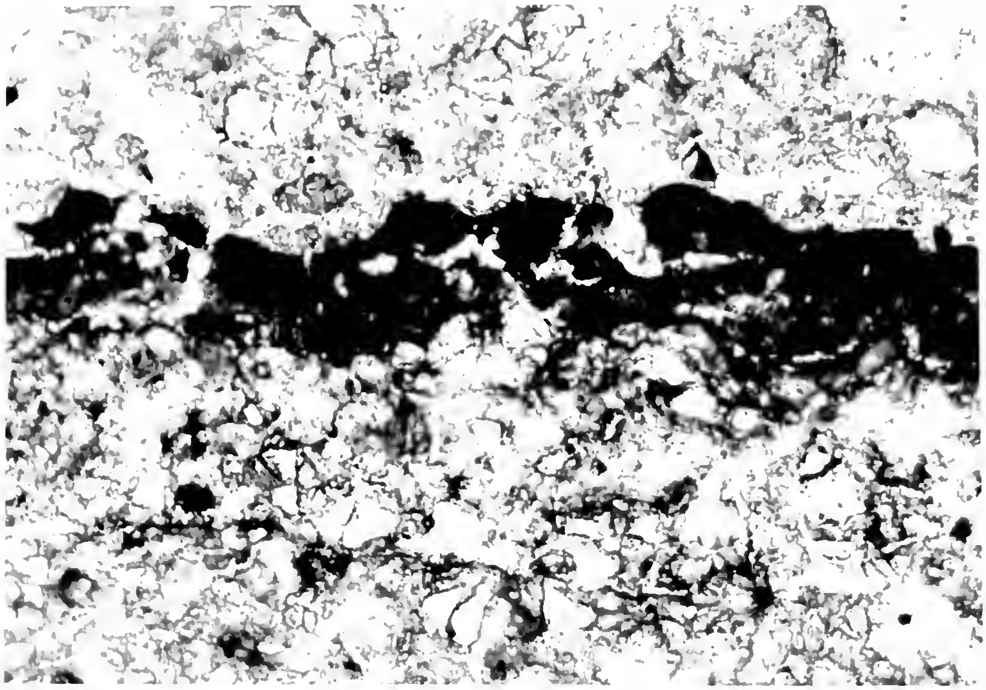


Figure 22. Sample 6 thin section. Plane polarized light, 100x magnification.

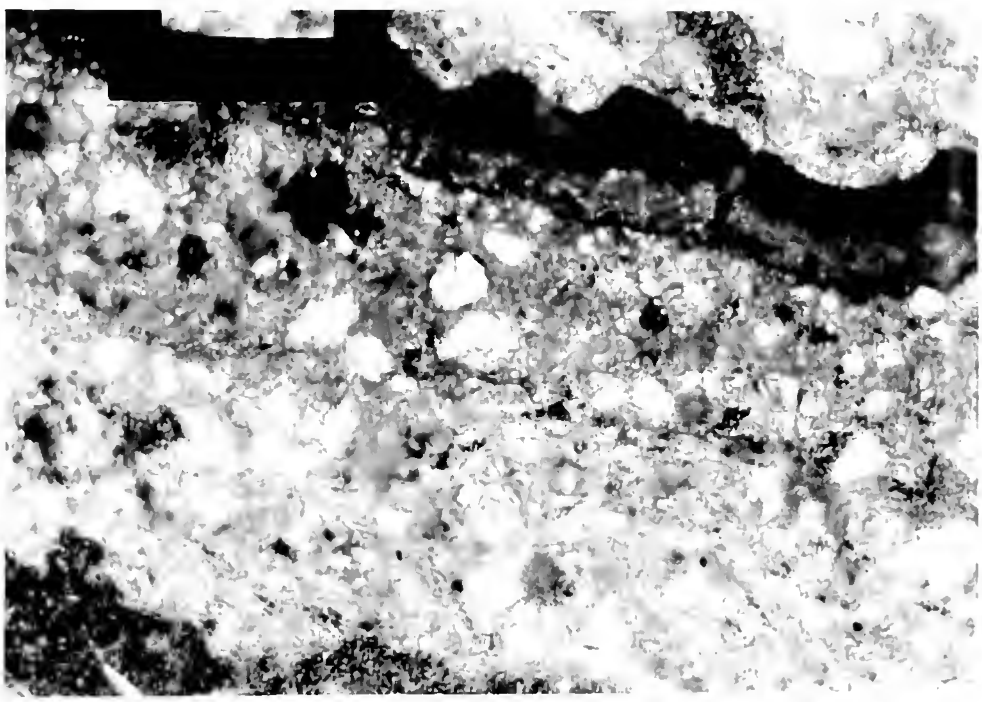


Figure 23. Sample 6 thin section. Cross polarized light, 100x magnification.

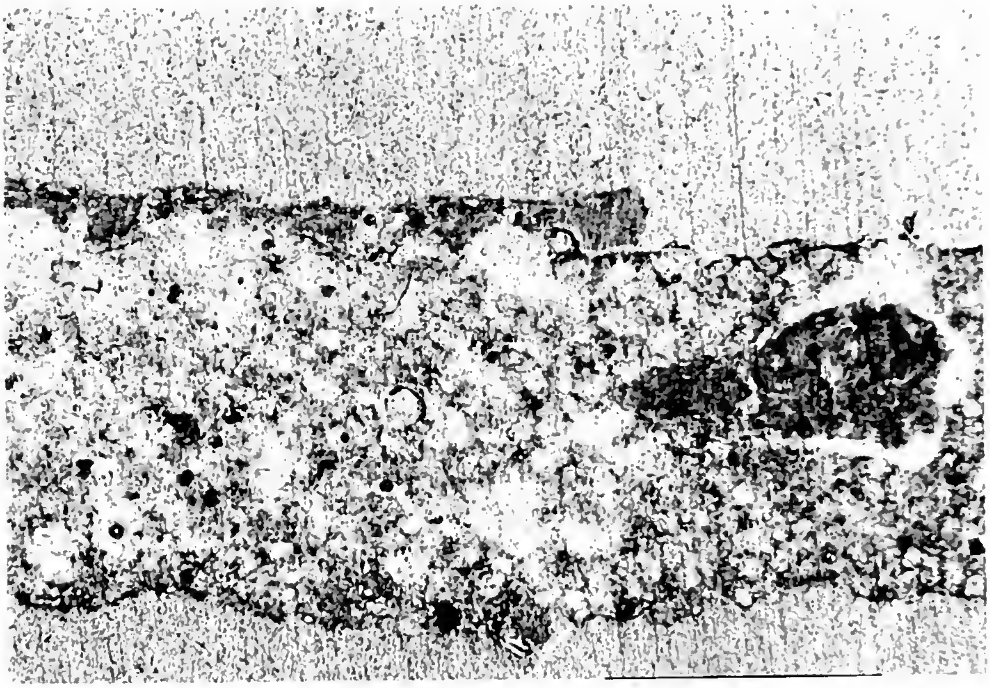


Figure 24. Sample 10 thin section. Plane polarized light, 25x magnification.

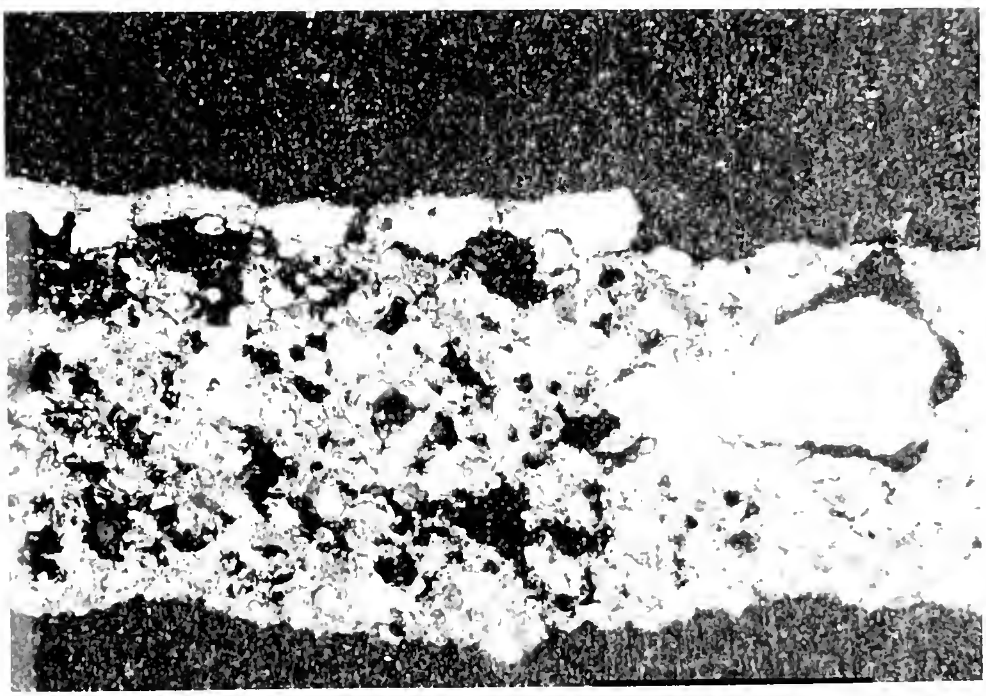


Figure 25. Sample 10 thin section. Cross polarized light, 25x magnification.

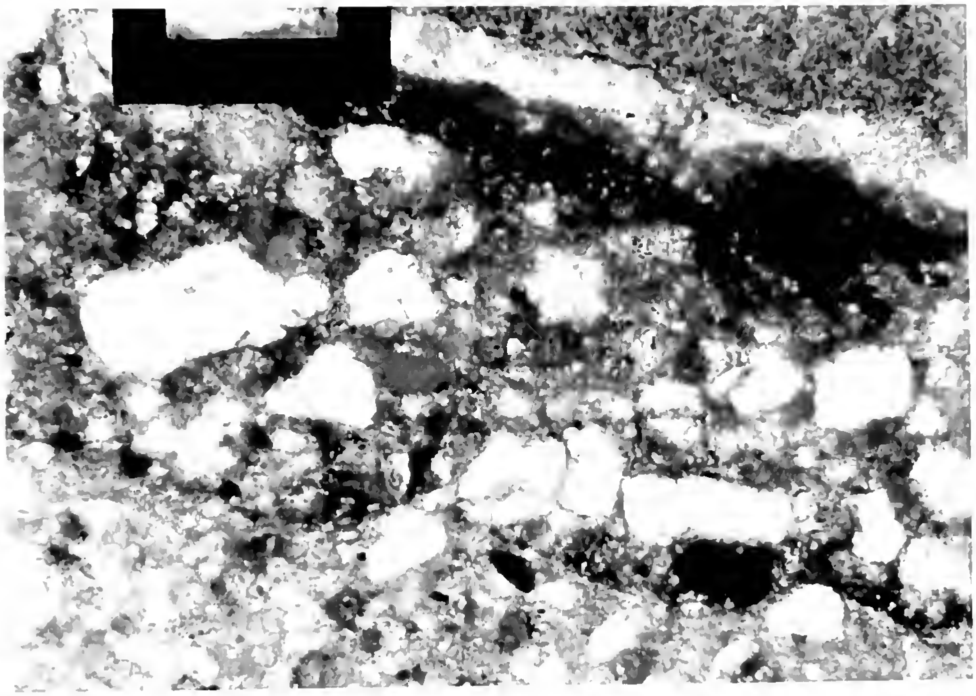


Figure 26. Sample 11b thin section. Cross polarized light, 100x magnification. Fractured quartz grains.

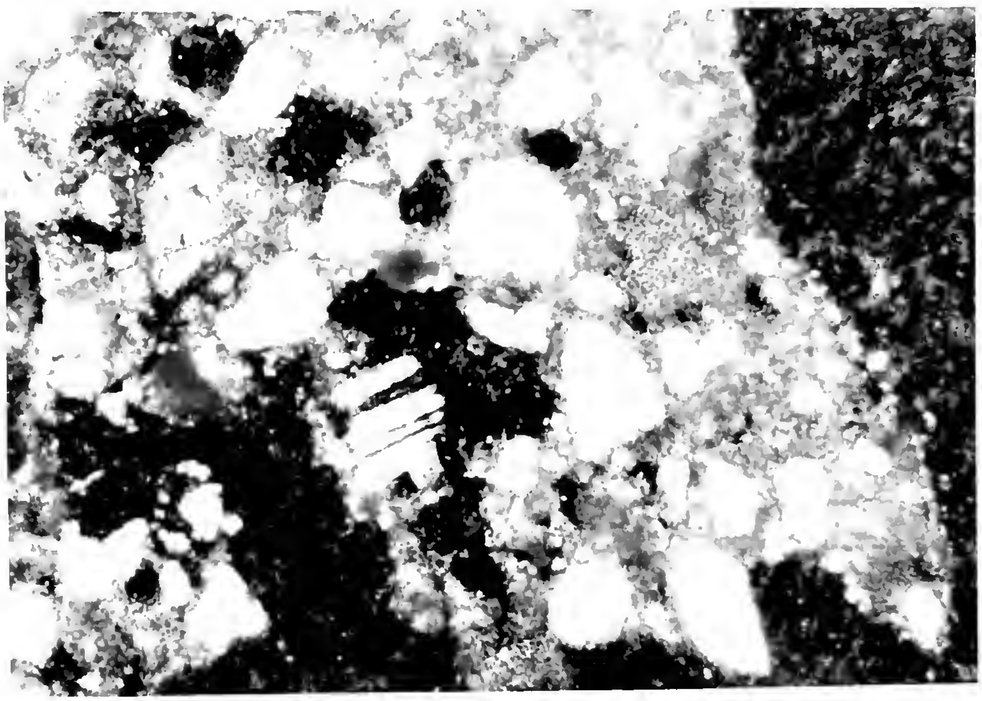


Figure 27. Sample 8 thin section. Cross polarized light, 100x magnification. Feldspar twinning.

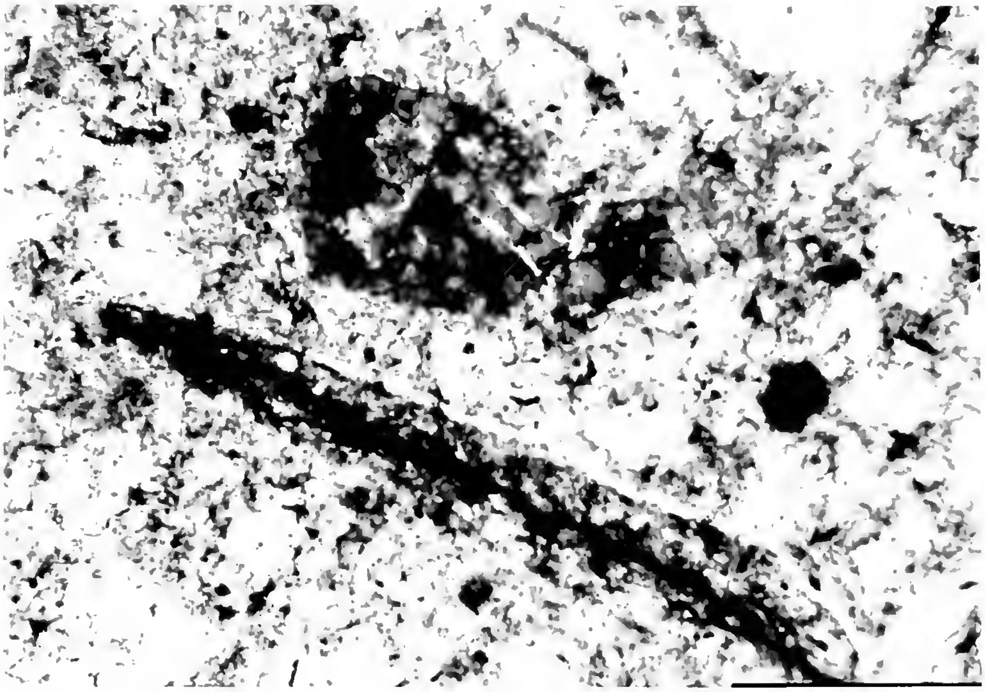


Figure 28. Sample 4 thin section. Plane polarized light, 100x magnification. Ferromagnesium particles in matrix.

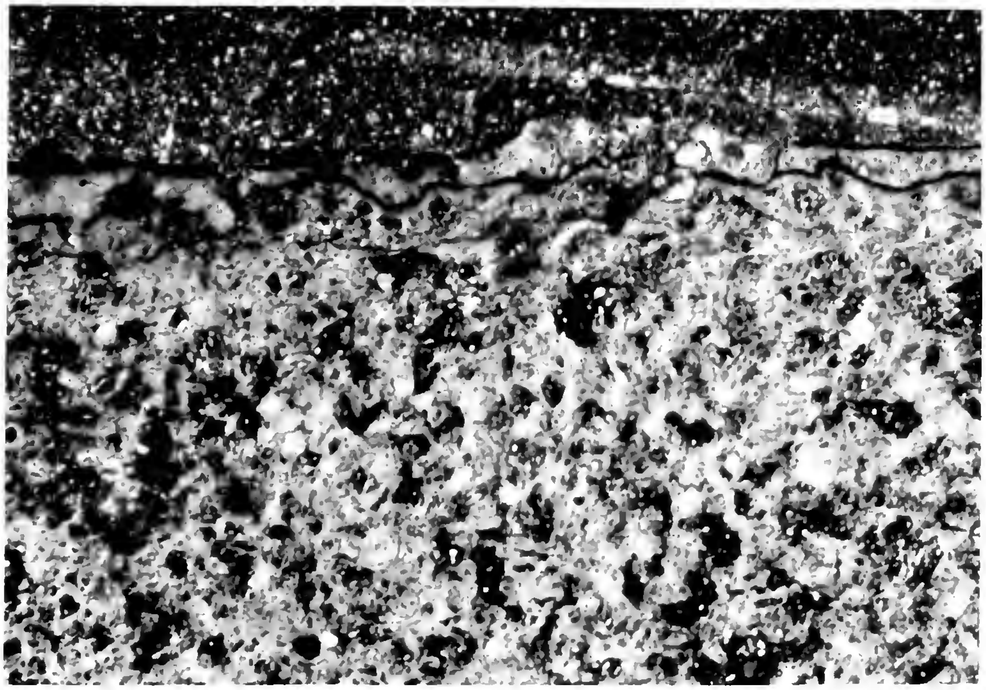


Figure 29. Sample 2 thin section. Pseudo-darkfield reflected light, 10x magnification. Juncture of red and white finishes in one layer.

APPENDIX A

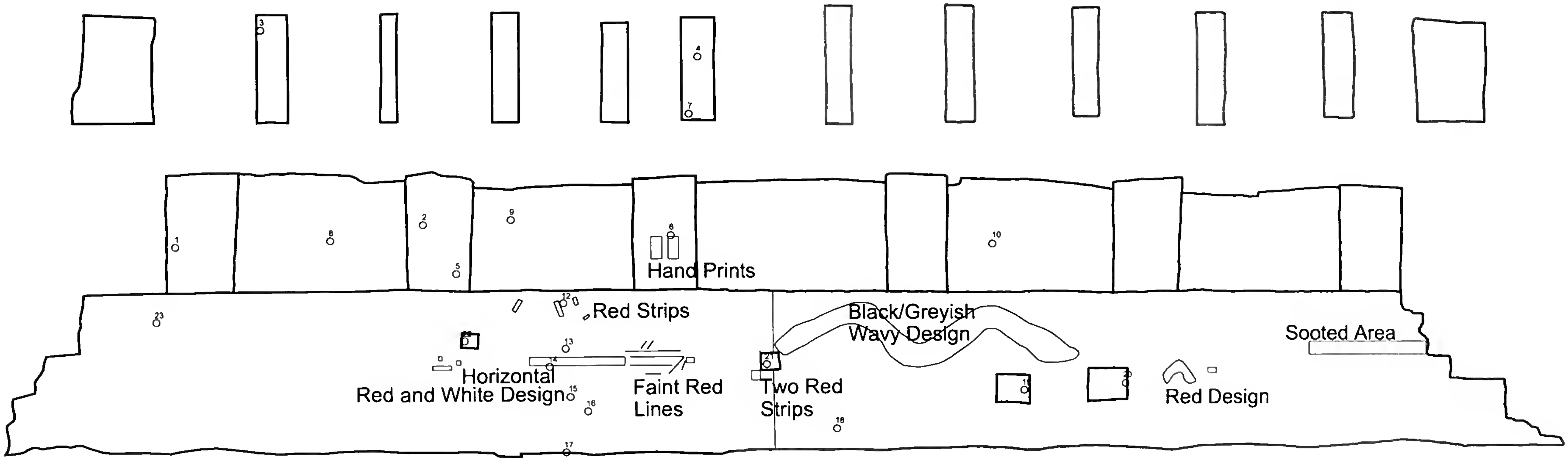
SAMPLE LIST

KIVA Q SAMPLE LIST

Cliff Palace

Mesa Verde National Park

Sample	Location	Comments
01	Pilaster 1	Extruded smooth, red and black layers
01	Pilaster 2	From stone, not mortar joint
03	Pilaster 1: 1E	Extruded smooth from joint: grey
04	Pilaster 3: 3E	Feather edge of extruded
05	Pilaster 2	From stone
06	Pilaster 3	Near joint, possibly some extruded
07	Pilaster 3: 3E	Right side of pilaster
08	Section 3B	Recess
09	Section 4B	Recess, over mortar joint
10	Section 7B	Recess
11	Pilaster 3	Juncture of banquette lip and pilaster bottom
12	Section 4A	Not a complete cross section, but includes white
13	Section 4A	Over mortar joint
14	Section 4A	Decorative band (lower)
15	Section 4A	Below decorative band—broken (crush for analysis)
16	Section 5A	Below decorative band (red dado)
17	Section 4A	Juncture of kiva wall and floor
18	Section 6A	Two chunks: 18a, 18b
19	Niche 3	Right wall, 4" in, and mortar from rear stone (vert. joint)
20	Niche 4	Right wall inner lip before stone inset (1" in)
21	Niche 2	Over rear bottom mortar joint
22	Niche 1	Left wall, from stone
23	Section 1A	1934 repair


Hand Prints
Red Strips
Black/Greyish
Wavy Design
Sooted Area
Horizontal
Red and White Design
Faint Red
Lines
Two Red
Strips
Red Design

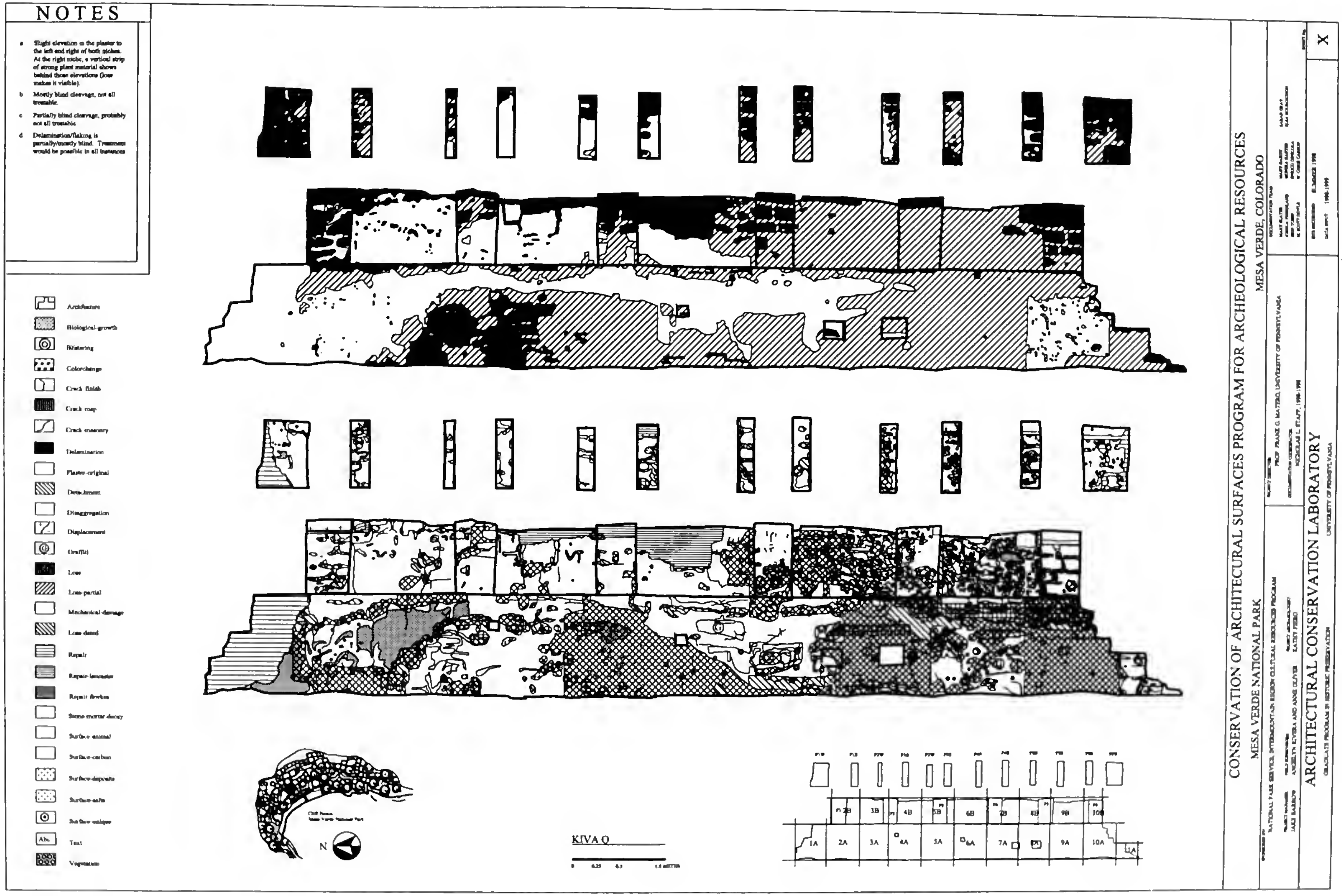
APPENDIX C

CONDITIONS SURVEY

Kiva Q

Cliff Palace

Mesa Verde National Park


NOTES
a Slight elevation in the plaster to the left and right of both niches. At the right niche, a vertical strip of strong plant material shows behind those elevations (loss makes it visible).
b Mostly blind cleavage, not all treatable.
c Partially blind cleavage, probably not all treatable
d Delamination/flaking is partially/mostly blind. Treatment would be possible in all instances
Architecture
Biological-growth
Blistering
Colorchange
Crack finish
Crack map
Crack masonry
Delamination
Plaster-original
Detachment
Disaggregation
Displacement
Graffiti
Loss
Loss partial
Mechanical-damage
Loss dated
Repair
Repair-lancaster
Repair fewkes
Stone mortar decay
Surface-animal
Surface-carbon
Surface-deposits
Surface-salts
Surface-unique
Text
Vegetation
N
KIVA Q
1A
2A
3A
4A
5A
6A
7A
8A
9A
10A
11A
2B
3B
4B
5B
6B
7B
8B
9B
10B
CONSERVATION OF ARCHITECURAL SURFACES PROGRAM FOR ARCHEOLOGICAL RESOURCES
MESA VERDE, COLORADO
MESA VERDE NATIONAL PARK
ARCHITECTURAL CONSERVATION LABORATORY
X

APPENDIX D

STRATIGRAPHIES OBSERVED IN KIVA Q

Cliff Palace

Mesa Verde National Park

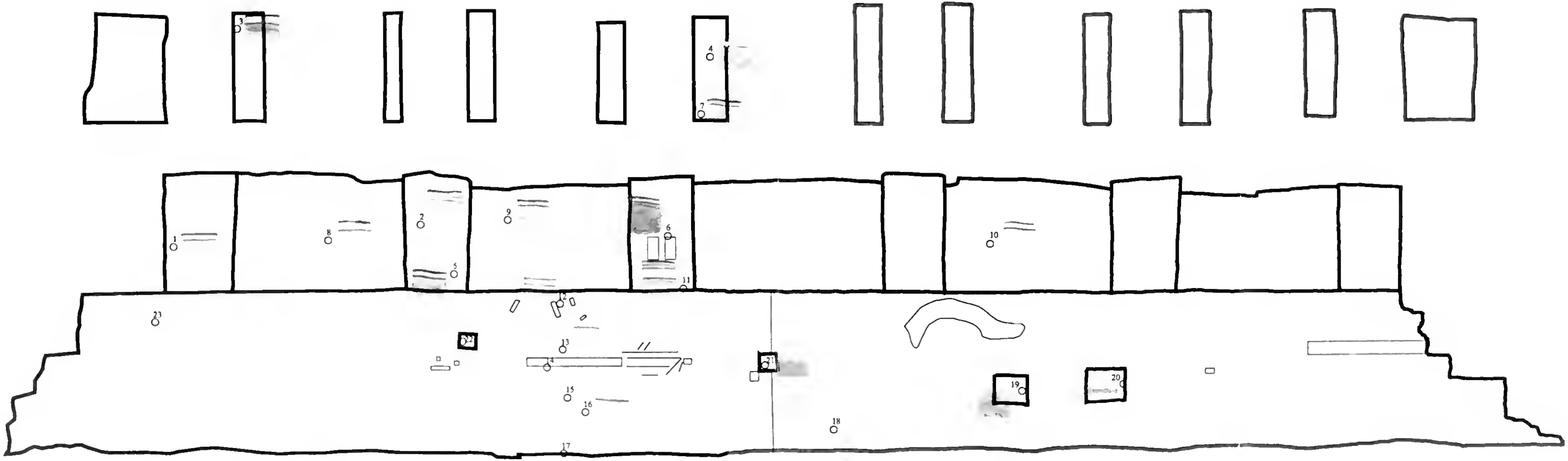
STRATIGRAPHIES OBSERVED IN KIVA Q

Cliff Palace

Mesa Verde National Park

Substrate ↔ Surface

Layer	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23
1	Black	Black	Black	White	Buff	Buff	Buff	Black	Black	Black	Brown	White	Buff	White	Buff	Buff	Red/ Orange	Buff	Red/ Orange	Buff	White	Buff
2	Red/ Orange	R/O. White	Red/ Orange	Red/ Brown	Black	Black	Black	White	Red	White	Red	Grey/ Black	Brown	Buff	Grey Brown	Buff	Buff	Grey/ Tan	Grey/ Tan	Grey/ Tan	Buff	
3	Black	Black	Black	Tan	Red	Red	Orange/ Brown	Red/ Orange	Black	Black	Brown	Buff	Buff		Buff		Orange/ Buff		Buff			
4	Brown	Orange/ Brown	Brown	Buff	Black	Black	Grey/ Brown	Black	Buff	Buff	Tan	Grey/ Black	White				Buff					
5	Tan	Brown/ Black	Tan		Brown/ Black	Tan	Buff	Buff	Tan		Brown	Buff	Buff									
6	Buff	Buff	Buff		Tan	Brown/ Grey			Buff		Buff		Buff									
7						Buff					White											
8											Red											
9											Black											
10											Tan											
11											Brown/ Grey											
12											Red											
13											Buff											



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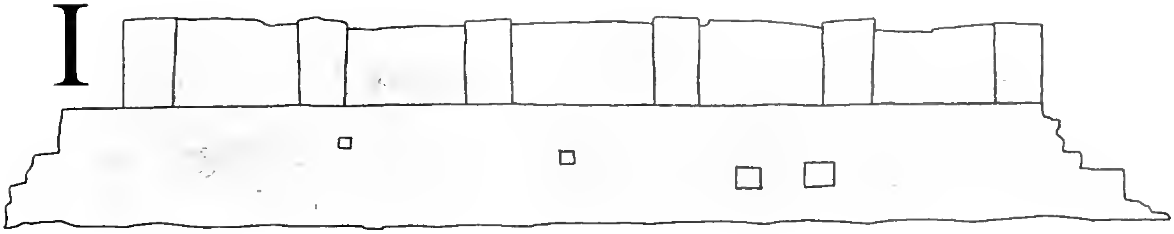
APPENDIX E

CONJECTURAL FINISH SCHEMES IN KIVA Q

Cliff Palace

Mesa Verde National Park

I



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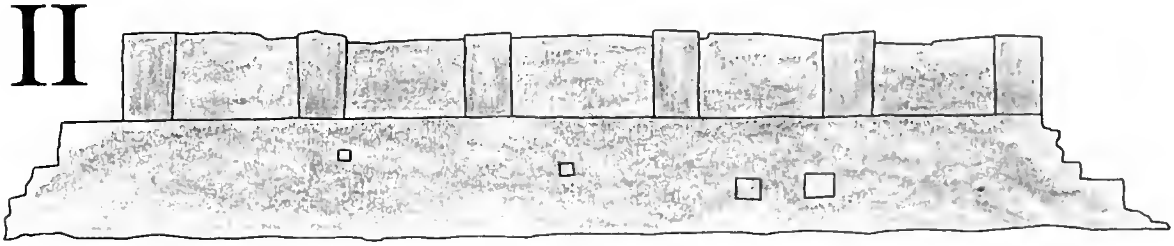

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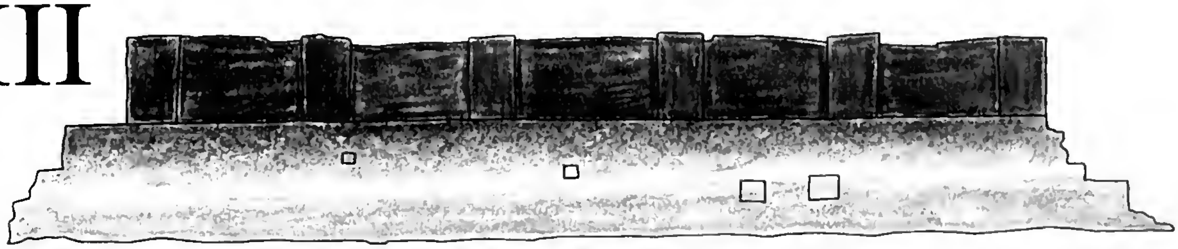

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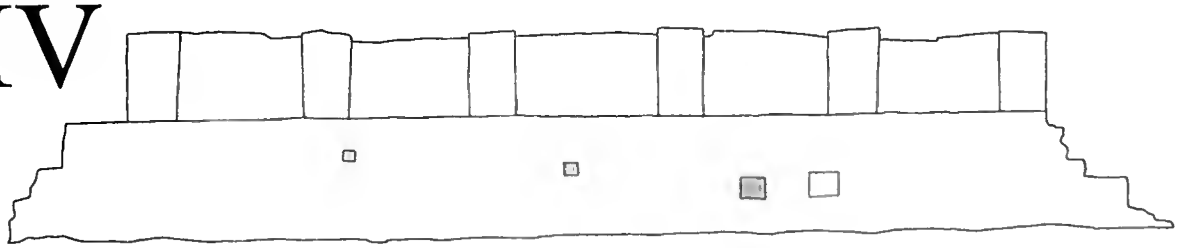

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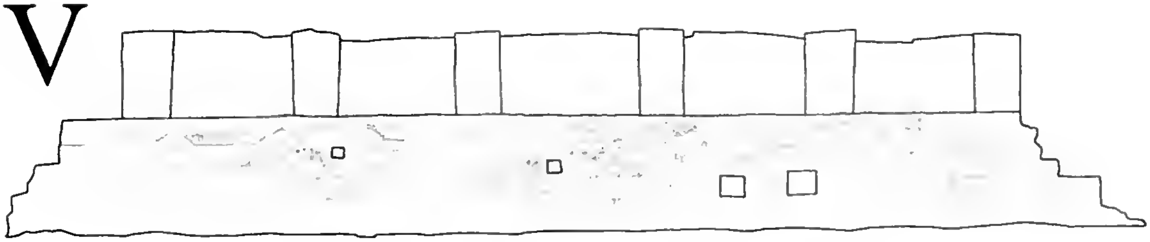

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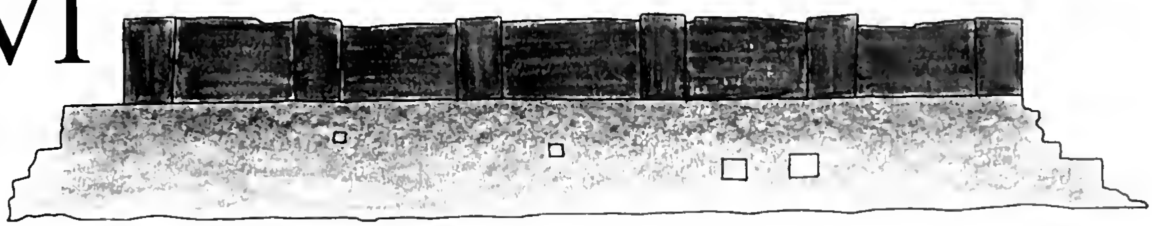
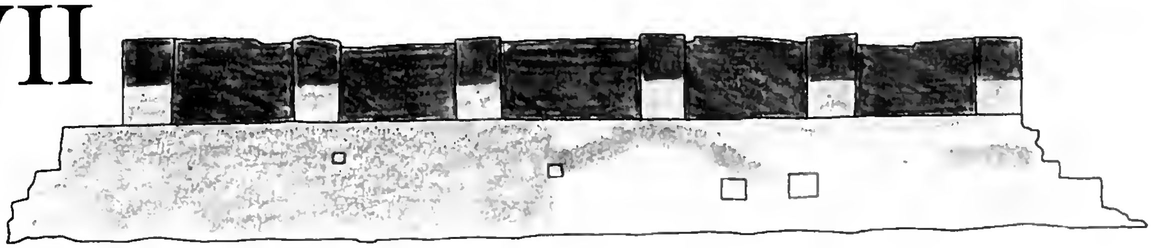


VII



APPENDIX F

THIN SECTION MICROMORPHOLOGY

Representative Sample Data Sheets

THIN SECTION DESCRIPTION: SAMPLE 6

Section 5B, Pilaster 3 (Face)

Substrate → Surface

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
Type	Plaster	Soot?	Wash	Soot	Wash	Soot	Wash
Thickness	Even	Even	Even	Even	Even	Even	Uneven
Measurement	1.54 mm	0.03 mm	0.23 mm	0.01 mm	0.78 mm	0.78 mm	0.26 mm
Texture	Heterog.	Heterog.	Homog.	Homog.	Homog.	Homog.	Heterog.
Anomalies							
Coarse/Fine Ratio	60 40	0:100	50 50	0.100	5 95	0:100	40.60
Layer Color	Buff	Brown/ Grey	Tan	Black	Red	Black	Buff
Matrix Colors	Orange, tan, red, black	Brown, black	Orange, tan, black, red	Black	Red, black, orange	Black, red	Tan, yellow, red
Coarse Fraction Colors	Clear, white	------	Clear, white	------	White	------	Clear
Coarse Fraction Roundness	Subrounded	------	Subangular	------	Subangular	------	Subrounded
Coarse Fraction Sorting	Poor	------	Poor	------	Poor	------	Poor

Comments: Ferromagnesium minerals stain the matrix of several layers. Some quartz grains are fractured, indicative of crushing.

THIN SECTION DESCRIPTION: SAMPLE 10

Section 7B, Upper Kiva Wall (Recess)

Substrate → Surface

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
Type	Plaster	Plaster	Wash	Plaster	Dirt	Wash
Thickness	Even	Even	Even	Even	Even	Uneven
Measurement	2.57 mm	2.44 mm	0.39 mm	1.03 mm	0.03 mm	0.26 mm
Texture	Homog	Homog	Homog	Homog	Heterog	Homog
Anomalies	micas			Orange, red inclusions		
Coarse/Fine Ratio	60:40	50:50	5:95	40:60	0:100	50:50
Layer Color	Buff	Buff	White	Buff	Brown	Buff
Matrix Colors	Tan, orange, black	Tan, yellow, black, red	white	Tan, orange, red, pink	Brown, tan, black	Tan, orange, red
Coarse Fraction Colors	Clear, white, yellow, red	Clear, white, brown	clear	Clear, white, yellow	------	Clear, white
Coarse Fraction Roundness	Subrounded	Subangular	Subrounded	Subrounded	------	Subangular
Coarse Fraction Sorting	Moderate	Poor	Poor	Moderate	------	Moderate

Comments: Ferromagnesium minerals stain the matrix of several layers. Some quartz grains are fractured, indicative of crushing.

THIN SECTION DESCRIPTION: SAMPLE 11

Section 5B, Junction of Banquette and Pilaster 3

Substrate → Surface

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9	Layer 10	Layer 11	Layer 12	Layer 13
Type	Plaster	Wash	Dirt	Plaster	Soot	Wash	Wash	Wash	Wash	Plaster	Wash	Wash	Wash
Thickness	Even	Uneven	Even	Even	Uneven	Uneven	Even	Even	Uneven	Even	Uneven	Uneven	Uneven
Measurement	1.54 mm	0.05 mm	0.03 mm	0.51 mm	0.12 mm	0.08 mm	0.08 mm	0.64 mm	0.05 mm	0.26 mm	0.05 mm	0.10 mm	0.03 mm
Texture	Heterog	Homog	Heterog	Heterog	Homog	Homog	Homog.	Homog	Heterog.	Heterog.	Heterog	Homog	Heterog.
Anomalies	Blebs (calcite?)						Blebs, inclusions			Red inclusion			
Coarse/Fine Ratio	50:50	0:100	0:100	50:50	0:100	0:100	0:100	50:50	0:100	50:50	5:95	5:95	0:100
Layer Color	Buff	Red/ Orange	Brown/ Grey	Tan	Black	Orange/ Red	White	Buff	Brown	Tan	Brown	Red	Brown
Matrix Colors	Tan, red, Black, orange	Red, orange, tan	Black, tan	Red, black, tan, orange	Black, brown, tan	Red, tan, orange	white	Tan, white, black, orange	Brown, black	Orange, tan, red, black	Brown, black, red	Red, orange, tan, black	Brown, black, tan, red
Coarse Fraction Colors	Clear, white, yellow	------	------	Clear, white	------	------	------	Clear, white	------	Clear, white	Clear	Clear	------
Coarse Fraction Roundness	Subangular	------	------	Subangular	------	------	------	Subrounded	------	Subangular	Subangular	Subangular	------
Coarse Fraction Sorting	Poor	------	------	Poor	------	------	------	Moderate	------	Moderate	Poor	Poor	------

Comments: Sample fractured during preparation, separated into 11b (base) and 11f (finish). Some quartz grains are fractured, indicative of crushing. Larger grains grouped near center of thin section 11b.

THIN SECTION DESCRIPTION: SAMPLE 13

Section 4A, Banquette

Substrate → Surface

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
Type	Plaster	Plaster	Wash	Plaster	Dirt	Wash
Thickness	Even	Even	Even	Even	Even	Uneven
Measurement	2.57 mm	2.44 mm	0.39 mm	1.03 mm	0.03 mm	0.26 mm
Texture	Homog	Homog	Homog	Homog	Heterog	Homog
Anomalies	micas			Orange, red inclusions		
Coarse/Fine Ratio	60:40	50:50	5:95	40:60	0:100	50:50
Layer Color	Buff	Buff	White	Buff	Brown	Buff
Matrix Colors	Tan, orange, black	Tan, yellow, black, red	white	Tan, orange, red, pink	Brown, tan, black	Tan, orange, red
Coarse Fraction Colors	Clear, white, yellow, red	Clear, white, brown	clear	Clear, white, yellow	------	Clear, white
Coarse Fraction Roundness	Subrounded	Subangular	Subrounded	Subrounded	------	Subangular
Coarse Fraction Sorting	Moderate	Poor	Poor	Moderate	------	Moderate

Comments: Sample fractured during preparation, separated into 13b (bas) and 13f (finish)Ferromagnesium minerals stain the matrix of several layers. Some quartz grains are fractured, indicative of crushing. Large, flaky inclusion: biotite? Some fossils present.

THIN SECTION DESCRIPTION: SAMPLE 18

Section 6A, Banquette

Substrate → Surface

	Layer 1	Layer 2	Layer 3	Layer 4
Type	Plaster	Wash	Plaster	Wash
Thickness	Even	Even	Even	Even
Measurement	2.57 mm	0.03 mm	5.14 mm	0.13 mm
Texture	Heterog	Homog	Heterog	Homog.
Anomalies	Large inclusion		Large red and tan inclusions	Large red inclusion
Coarse/Fine Ratio	50:50	0:100	60:40	5:95
Layer Color	Buff	Orange/ buff	Buff	Red/ Orange
Matrix Colors	Tan, orange, black	orange	Tan, orange, yellow, red, black	Orange, black
Coarse Fraction Colors	Clear, white, red, black, pink, yellow	------	Clear, white	Clear
Coarse Fraction Roundness	Subrounded	------	Subangular	Subangular
Coarse Fraction Sorting	Moderate	------	Moderate	Poor

Comments: Some quartz grains are fractured, indicative of crushing. Large calcareous and iron inclusions. Boundary between layer 1 and 2 very indistinct.

APPENDIX G

GRAIN SIZE MEASUREMENTS

Data Sheets

Sample 2 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	8	7	0.08	0.07	0.02	Sand
	7	4	0.07	0.04	0.0092	Sand
	8	4	0.08	0.04	0.0105	Sand
	3	2	0.03	0.02	0.0020	Silt
	4	1	0.04	0.01	0.0013	Silt
	3	3	0.03	0.03	0.0029	Silt
	10	9	0.10	0.09	0.0294	Sand
	12	8	0.12	0.08	0.0314	Sand
	6	5	0.06	0.05	0.0098	Sand
	4	4	0.04	0.04	0.0052	Silt
	7	5	0.07	0.05	0.0114	Sand
	7	5	0.07	0.05	0.0114	Sand
	4	3	0.04	0.03	0.0039	Silt
	5	2	0.05	0.02	0.0033	Silt
	4	3	0.04	0.03	0.0039	Silt
	3	2	0.03	0.02	0.0020	Silt
	11	7	0.11	0.07	0.0252	Sand
	3	3	0.03	0.03	0.0029	Silt
	7	3	0.07	0.03	0.0069	Sand
	11	7	0.11	0.07	0.0252	Sand
	4	1	0.04	0.01	0.0013	Silt
	3	3	0.03	0.03	0.0029	Silt
	9	4	0.09	0.04	0.0118	Sand
	7	5	0.07	0.05	0.0114	Sand
	3	3	0.03	0.03	0.0029	Silt
	5	2	0.05	0.02	0.0033	Sand
	9	6	0.09	0.06	0.0177	Sand
	4	3	0.04	0.03	0.0039	Silt
	2	2	0.02	0.02	0.0013	Silt
	4	3	0.04	0.03	0.0039	Silt
Average (mm)	5.9	4.0	0.060	0.040	0.0077	
Median (mm)			0.05	0.03	0.0049	
Standard Deviation (mm)			0.029	0.021	0.009	

Sample 2 grains: 50% sand
50% silt

Major Axis Size Range: 0.12-0.02 mm
Minor Axis Size Range: 0.09-0.01 mm

Sample 3 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	16	8	0.16	0.08	0.04	Sand
	9	8	0.09	0.08	0.0236	Sand
	13	8	0.13	0.08	0.0340	Sand
	5	2	0.05	0.02	0.0033	Silt
	12	11	0.12	0.11	0.0432	Sand
	4	3	0.04	0.03	0.0039	Silt
	10	6	0.10	0.06	0.0196	Sand
	7	5	0.07	0.05	0.0114	Sand
	12	8	0.12	0.08	0.0314	Sand
	10	6	0.10	0.06	0.0196	Sand
	11	7	0.11	0.07	0.0252	Sand
	10	7	0.10	0.07	0.0229	Sand
	3	2	0.03	0.02	0.0020	Silt
	11	8	0.11	0.08	0.0288	Sand
	10	5	0.10	0.05	0.0164	Sand
	6	4	0.06	0.04	0.0079	Sand
	13	9	0.13	0.09	0.0383	Sand
	7	6	0.07	0.06	0.0137	Sand
	12	11	0.12	0.11	0.0432	Sand
	15	6	0.15	0.06	0.0294	Sand
	10	6	0.10	0.06	0.0196	Sand
	6	3	0.06	0.03	0.0059	Sand
	11	7	0.11	0.07	0.0252	Sand
	8	5	0.08	0.05	0.0131	Sand
	11	10	0.11	0.10	0.0360	Sand
	12	8	0.12	0.08	0.0314	Sand
	9	5	0.09	0.05	0.0147	Sand
	12	5	0.12	0.05	0.0196	Sand
	10	7	0.10	0.07	0.0229	Sand
	5	3	0.05	0.03	0.0049	Silt
Average (mm)	9.666667	6.3	0.099	0.064	0.0199	
Median (mm)			0.10	0.06	0.0196	
Standard Deviation (mm)			0.032	0.025	0.012	

Sample 3 grains: 87% sand
13% silt

Major Axis Size Range: 0.16-0.03 mm
Minor Axis Size Range: 0.11-0.02 mm

Sample 4 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	16	10	0.16	0.10	0.05	Sand
	14	13	0.14	0.13	0.0595	Sand
	15	6	0.15	0.06	0.0294	Sand
	8	6	0.08	0.06	0.0157	Sand
	12	10	0.12	0.10	0.0393	Sand
	13	8	0.13	0.08	0.0340	Sand
	7	5	0.07	0.05	0.0114	Sand
	20	10	0.20	0.10	0.0654	Sand
	9	9	0.09	0.09	0.0265	Sand
	10	7	0.10	0.07	0.0229	Sand
	15	5	0.15	0.05	0.0245	Sand
	11	6	0.11	0.06	0.0216	Sand
	15	5	0.15	0.05	0.0245	Sand
	10	5	0.10	0.05	0.0164	Sand
	5	5	0.05	0.05	0.0082	Silt
	12	10	0.12	0.10	0.0393	Sand
	10	9	0.10	0.09	0.0294	Sand
	14	11	0.14	0.11	0.0504	Sand
	7	7	0.07	0.07	0.0160	Sand
	13	9	0.13	0.09	0.0383	Sand
	5	3	0.05	0.03	0.0049	Silt
	11	8	0.11	0.08	0.0288	Sand
	15	11	0.15	0.11	0.0540	Sand
	8	5	0.08	0.05	0.0131	Sand
	7	5	0.07	0.05	0.0114	Sand
	15	7	0.15	0.07	0.0343	Sand
	11	9	0.11	0.09	0.0324	Sand
	5	3	0.05	0.03	0.0049	Sand
	10	6	0.10	0.06	0.0196	Silt
	8	13	0.08	0.13	0.0340	Sand
Average (mm)	11.03333	7.5	0.113	0.077	0.0272	
Median (mm)			0.11	0.07	0.0252	
Standard Deviation (mm)			0.038	0.028	0.016	

Sample 4 grains: 90% sand
10% silt

Major Axis Size Range: 0.20-0.05 mm
Minor Axis Size Range: 0.13-0.03 mm

Sample 5 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	8	8	0.08	0.08	0.02	Sand
	11	5	0.11	0.05	0.0180	Sand
	8	8	0.08	0.08	0.0209	Sand
	10	6	0.10	0.06	0.0196	Sand
	6	5	0.06	0.05	0.0098	Sand
	6	4	0.06	0.04	0.0079	Sand
	7	6	0.07	0.06	0.0137	Sand
	5	5	0.05	0.05	0.0082	Silt
	7	4	0.07	0.04	0.0092	Sand
	5	4	0.05	0.04	0.0065	Silt
	10	4	0.10	0.04	0.0131	Sand
	10	5	0.10	0.05	0.0164	Sand
	7	6	0.07	0.06	0.0137	Sand
	9	7	0.09	0.07	0.0206	Sand
	5	5	0.05	0.05	0.0082	Silt
	6	5	0.06	0.05	0.0098	Sand
	6	4	0.06	0.04	0.0079	Sand
	9	5	0.09	0.05	0.0147	Sand
	9	4	0.09	0.04	0.0118	Sand
	5	3	0.05	0.03	0.0049	Silt
	9	6	0.09	0.06	0.0177	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	3	0.05	0.03	0.0049	Silt
	2	2	0.02	0.02	0.0013	Silt
	4	3	0.04	0.03	0.0039	Silt
	7	3	0.07	0.03	0.0069	Sand
	6	3	0.06	0.03	0.0059	Sand
	4	3	0.04	0.03	0.0039	Silt
	6	3	0.06	0.03	0.0059	Sand
	12	8	0.12	0.08	0.0314	Sand
Average (mm)	7.066667	4.7	0.072	0.048	0.0109	
Median (mm)			0.07	0.05	0.0114	
Standard Deviation (mm)			0.024	0.017	0.007	

Sample 5 grains: 73% sand
27% silt

Major Axis Size Range: 0.12-0.02 mm
Minor Axis Size Range: 0.08-0.02 mm

Sample 6 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	7	6	0.07	0.06	0.01	Sand
	4	3	0.04	0.03	0.0039	Silt
	7	5	0.07	0.05	0.0114	Sand
	7	4	0.07	0.04	0.0092	Sand
	8	5	0.08	0.05	0.0131	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	4	0.05	0.04	0.0065	Silt
	3	2	0.03	0.02	0.0020	Silt
	5	3	0.05	0.03	0.0049	Silt
	6	3	0.06	0.03	0.0059	Sand
	6	4	0.06	0.04	0.0079	Sand
	9	5	0.09	0.05	0.0147	Sand
	4	3	0.04	0.03	0.0039	Silt
	7	4	0.07	0.04	0.0092	Sand
	13	7	0.13	0.07	0.0298	Sand
	15	2	0.15	0.02	0.0098	Sand
	3	3	0.03	0.03	0.0029	Silt
	13	7	0.13	0.07	0.0298	Sand
	9	7	0.09	0.07	0.0206	Sand
	10	5	0.10	0.05	0.0164	Sand
	3	2	0.03	0.02	0.0020	Silt
	2	1	0.02	0.01	0.0007	Silt
	4	3	0.04	0.03	0.0039	Silt
	10	7	0.10	0.07	0.0229	Sand
	6	2	0.06	0.02	0.0039	Sand
	4	3	0.04	0.03	0.0039	Silt
	4	2	0.04	0.02	0.0026	Silt
	4	3	0.04	0.03	0.0039	Silt
	6	4	0.06	0.04	0.0079	Sand
	4	4	0.04	0.04	0.0052	Silt
Average (mm)	6.533	3.933	0.067	0.040	0.0084	
Median (mm)			0.06	0.04	0.0079	
Standard Deviation (mm)			0.033	0.017	0.008	

Sample 6 grains: 57% sand
43% silt

Major Axis Size Range: 0.15-0.02 mm
Minor Axis Size Range: 0.07-0.01 mm

Sample 7 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	6	5	0.06	0.05	0.01	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	4	0.05	0.04	0.0065	Silt
	4	2	0.04	0.02	0.0026	Silt
	5	3	0.05	0.03	0.0049	Silt
	5	5	0.05	0.05	0.0082	Silt
	6	3	0.06	0.03	0.0059	Sand
	5	3	0.05	0.03	0.0049	Silt
	8	3	0.08	0.03	0.0079	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	3	0.05	0.03	0.0049	Silt
	2	2	0.02	0.02	0.0013	Silt
	4	2	0.04	0.02	0.0026	Silt
	6	2	0.06	0.02	0.0039	Sand
	4	3	0.04	0.03	0.0039	Silt
	6	4	0.06	0.04	0.0079	Sand
	6	3	0.06	0.03	0.0059	Sand
	5	4	0.05	0.04	0.0065	Silt
	5	4	0.05	0.04	0.0065	Silt
	6	3	0.06	0.03	0.0059	Sand
	3	2	0.03	0.02	0.0020	Silt
	3	1	0.03	0.01	0.0010	Silt
	2	2	0.02	0.02	0.0013	Silt
	5	3	0.05	0.03	0.0049	Silt
	5	4	0.05	0.04	0.0065	Silt
	2	1	0.02	0.01	0.0007	Silt
	2	2	0.02	0.02	0.0013	Silt
	4	3	0.04	0.03	0.0039	Silt
	5	4	0.05	0.04	0.0065	Silt
	7	5	0.07	0.05	0.0114	Sand
Average (mm)	4.900	3.167	0.050	0.032	0.0051	
Median (mm)			0.05	0.03	0.0049	
Standard Deviation (mm)			0.017	0.012	0.003	

Sample 7 grains: 33.3% sand
66.7% silt

Major Axis Size Range: 0.08-0.02 mm
Minor Axis Size Range: 0.05-0.01 mm

Sample 8 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	19	14	0.19	0.14	0.09	Sand
	10	8	0.10	0.08	0.0262	Sand
	12	7	0.12	0.07	0.0275	Sand
	9	4	0.09	0.04	0.0118	Sand
	5	7	0.05	0.07	0.0114	Silt
	6	3	0.06	0.03	0.0059	Sand
	5	3	0.05	0.03	0.0049	Silt
	13	8	0.13	0.08	0.0340	Sand
	9	8	0.09	0.08	0.0236	Sand
	13	7	0.13	0.07	0.0298	Sand
	9	7	0.09	0.07	0.0206	Sand
	10	5	0.10	0.05	0.0164	Sand
	13	6	0.13	0.06	0.0255	Sand
	12	8	0.12	0.08	0.0314	Sand
	9	7	0.09	0.07	0.0206	Sand
	6	3	0.06	0.03	0.0059	Sand
	13	4	0.13	0.04	0.0170	Sand
	7	5	0.07	0.05	0.0114	Sand
	3	2	0.03	0.02	0.0020	Silt
	16	10	0.16	0.10	0.0523	Sand
	5	4	0.05	0.04	0.0065	Silt
	11	9	0.11	0.09	0.0324	Sand
	9	8	0.09	0.08	0.0236	Sand
	12	6	0.12	0.06	0.0236	Sand
	18	10	0.18	0.10	0.0589	Sand
	19	12	0.19	0.12	0.0746	Sand
	12	8	0.12	0.08	0.0314	Sand
	5	4	0.05	0.04	0.0065	Silt
	5	4	0.05	0.04	0.0065	Silt
	4	3	0.04	0.03	0.0039	Silt
Average (mm)	9.967	6.467	0.102	0.066	0.0211	
Median (mm)			0.10	0.07	0.0218	
Standard Deviation (mm)			0.045	0.029	0.021	

Sample 8 grains: 77% sand
23% silt

Major Axis Size Range: 0.19-0.03 mm
Minor Axis Size Range: 0.14-0.02 mm

Sample 9 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	20	10	0.20	0.10	0.07	Sand
	13	9	0.13	0.09	0.0383	Sand
	9	5	0.09	0.05	0.0147	Sand
	15	9	0.15	0.09	0.0442	Sand
	9	9	0.09	0.09	0.0265	Sand
	2	2	0.02	0.02	0.0013	Silt
	8	5	0.08	0.05	0.0131	Sand
	15	8	0.15	0.08	0.0393	Sand
	7	5	0.07	0.05	0.0114	Sand
	14	9	0.14	0.09	0.0412	Sand
	4	2	0.04	0.02	0.0026	Silt
	5	3	0.05	0.03	0.0049	Silt
	5	3	0.05	0.03	0.0049	Silt
	3	2	0.03	0.02	0.0020	Silt
	4	2	0.04	0.02	0.0026	Silt
	4	3	0.04	0.03	0.0039	Silt
	3	2	0.03	0.02	0.0020	Silt
	3	2	0.03	0.02	0.0020	Silt
	3	2	0.03	0.02	0.0020	Silt
	4	2	0.04	0.02	0.0026	Silt
	12	8	0.12	0.08	0.0314	Sand
	10	4	0.10	0.04	0.0131	Sand
	13	11	0.13	0.11	0.0468	Sand
	9	5	0.09	0.05	0.0147	Sand
	3	2	0.03	0.02	0.0020	Silt
	15	12	0.15	0.12	0.0589	Sand
	14	13	0.14	0.13	0.0595	Sand
	7	4	0.07	0.04	0.0092	Sand
	14	6	0.14	0.06	0.0275	Sand
	6	3	0.06	0.03	0.0059	Sand
Average (mm)	8.433	5.400	0.086	0.055	0.0149	
Median (mm)			0.08	0.05	0.0110	
Standard Deviation (mm)			0.051	0.036	0.020	

Sample 9 grains: 60% sand
40% silt

Major Axis Size Range: 0.20-0.02 mm
Minor Axis Size Range: 0.13-0.02 mm

Sample 10 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	22	13	0.22	0.13	0.09	Sand
	12	9	0.12	0.09	0.0353	Sand
	19	10	0.19	0.10	0.0622	Sand
	8	6	0.08	0.06	0.0157	Sand
	5	4	0.05	0.04	0.0065	Silt
	10	5	0.10	0.05	0.0164	Sand
	13	8	0.13	0.08	0.0340	Sand
	7	3	0.07	0.03	0.0069	Sand
	7	2	0.07	0.02	0.0046	Sand
	10	7	0.10	0.07	0.0229	Sand
	10	4	0.10	0.04	0.0131	Sand
	5	3	0.05	0.03	0.0049	Silt
	3	3	0.03	0.03	0.0029	Silt
	1	1	0.01	0.01	0.0003	Silt
	6	4	0.06	0.04	0.0079	Sand
	7	4	0.07	0.04	0.0092	Sand
	11	7	0.11	0.07	0.0252	Sand
	13	7	0.13	0.07	0.0298	Sand
	5	3	0.05	0.03	0.0049	Silt
	5	2	0.05	0.02	0.0033	Silt
	10	7	0.10	0.07	0.0229	Sand
	16	5	0.16	0.05	0.0262	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	2	0.05	0.02	0.0033	Silt
	11	5	0.11	0.05	0.0180	Sand
	33	14	0.33	0.14	0.1511	Sand
	10	5	0.10	0.05	0.0164	Sand
	5	3	0.05	0.03	0.0049	Silt
	1	9	0.01	0.09	0.0029	Silt
	10	5	0.10	0.05	0.0164	Sand
Average (mm)	9.600	5.500	0.098	0.056	0.0173	
Median (mm)			0.09	0.05	0.0147	
Standard Deviation (mm)			0.066	0.032	0.031	

Sample 10 grains: 70% sand
30% silt

Major Axis Size Range: 0.33-0.01 mm
Minor Axis Size Range: 0.14-0.01 mm

Sample 11 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	32	13	0.32	0.13	0.14	Sand
	10	8	0.10	0.08	0.0262	Sand
	22	7	0.22	0.07	0.0504	Sand
	15	9	0.15	0.09	0.0442	Sand
	15	13	0.15	0.13	0.0638	Sand
	9	8	0.09	0.08	0.0236	Sand
	9	5	0.09	0.05	0.0147	Sand
	20	10	0.20	0.10	0.0654	Sand
	11	9	0.11	0.09	0.0324	Sand
	13	9	0.13	0.09	0.0383	Sand
	8	6	0.08	0.06	0.0157	Sand
	10	5	0.10	0.05	0.0164	Sand
	3	3	0.03	0.03	0.0029	Silt
	8	6	0.08	0.06	0.0157	Sand
	4	4	0.04	0.04	0.0052	Silt
	8	3	0.08	0.03	0.0079	Sand
	7	6	0.07	0.06	0.0137	Sand
	5	3	0.05	0.03	0.0049	Silt
	8	6	0.08	0.06	0.0157	Sand
	3	3	0.03	0.03	0.0029	Silt
	8	7	0.08	0.07	0.0183	Sand
	5	4	0.05	0.04	0.0065	Silt
	13	7	0.13	0.07	0.0298	Sand
	11	7	0.11	0.07	0.0252	Sand
	6	5	0.06	0.05	0.0098	Sand
	5	4	0.05	0.04	0.0065	Silt
	20	16	0.20	0.16	0.1047	Sand
	5	3	0.05	0.03	0.0049	Silt
	9	9	0.09	0.09	0.0265	Sand
	7	7	0.07	0.07	0.0160	Sand
Average (mm)	10.300	6.833	0.105	0.070	0.0230	
Median (mm)			0.09	0.07	0.0181	
Standard Deviation (mm)			0.065	0.033	0.030	

Sample 11 grains: 77% sand
23% silt

Major Axis Size Range: 0.32-0.03 mm
Minor Axis Size Range: 0.16-0.03 mm

Sample 12 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	20	18	0.20	0.18	0.12	Sand
	20	15	0.20	0.15	0.0981	Sand
	12	7	0.12	0.07	0.0275	Sand
	10	7	0.10	0.07	0.0229	Sand
	8	6	0.08	0.06	0.0157	Sand
	5	3	0.05	0.03	0.0049	Silt
	6	5	0.06	0.05	0.0098	Sand
	10	7	0.10	0.07	0.0229	Sand
	7	5	0.07	0.05	0.0114	Sand
	5	3	0.05	0.03	0.0049	Silt
	8	5	0.08	0.05	0.0131	Sand
	7	5	0.07	0.05	0.0114	Sand
	5	3	0.05	0.03	0.0049	Silt
	7	5	0.07	0.05	0.0114	Sand
	3	2	0.03	0.02	0.0020	Silt
	2	2	0.02	0.02	0.0013	Silt
	3	3	0.03	0.03	0.0029	Silt
	6	5	0.06	0.05	0.0098	Sand
	6	4	0.06	0.04	0.0079	Sand
	12	8	0.12	0.08	0.0314	Sand
	6	2	0.06	0.02	0.0039	Sand
	19	12	0.19	0.12	0.0746	Sand
	16	14	0.16	0.14	0.0733	Sand
	11	10	0.11	0.10	0.0360	Sand
	5	3	0.05	0.03	0.0049	Silt
	16	10	0.16	0.10	0.0523	Sand
	11	9	0.11	0.09	0.0324	Sand
	6	4	0.06	0.04	0.0079	Sand
	3	2	0.03	0.02	0.0020	Silt
	4	3	0.04	0.03	0.0039	Silt
Average (mm)	8.633	6.233	0.088	0.064	0.0176	
Median (mm)			0.07	0.05	0.0114	
Standard Deviation (mm)			0.053	0.043	0.030	

Sample 12 grains: 70% sand
30% silt

Major Axis Size Range: 0.20-0.03 mm
Minor Axis Size Range: 0.18-0.02 mm

Sample 13 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	17	9	0.17	0.09	0.05	Sand
	10	7	0.10	0.07	0.0229	Sand
	5	2	0.05	0.02	0.0033	Silt
	5	5	0.05	0.05	0.0082	Silt
	6	5	0.06	0.05	0.0098	Sand
	16	9	0.16	0.09	0.0471	Sand
	3	2	0.03	0.02	0.0020	Silt
	6	6	0.06	0.06	0.0118	Sand
	4	4	0.04	0.04	0.0052	Silt
	7	5	0.07	0.05	0.0114	Sand
	3	2	0.03	0.02	0.0020	Silt
	7	4	0.07	0.04	0.0092	Sand
	12	5	0.12	0.05	0.0196	Sand
	9	4	0.09	0.04	0.0118	Sand
	7	5	0.07	0.05	0.0114	Sand
	17	12	0.17	0.12	0.0667	Sand
	19	8	0.19	0.08	0.0497	Sand
	9	7	0.09	0.07	0.0206	Sand
	3	2	0.03	0.02	0.0020	Silt
	11	9	0.11	0.09	0.0324	Sand
	7	6	0.07	0.06	0.0137	Sand
	5	3	0.05	0.03	0.0049	Silt
	10	7	0.10	0.07	0.0229	Sand
	4	3	0.04	0.03	0.0039	Silt
	10	6	0.10	0.06	0.0196	Sand
	18	10	0.18	0.10	0.0589	Sand
	11	7	0.11	0.07	0.0252	Sand
	5	4	0.05	0.04	0.0065	Silt
	5	2	0.05	0.02	0.0033	Silt
	9	7	0.09	0.07	0.0206	Sand
Average (mm)	8.667	5.567	0.088	0.057	0.0158	
Median (mm)			0.07	0.05	0.0114	
Standard Deviation (mm)			0.048	0.027	0.018	

Sample 13 grains: 66.7% sand **Major Axis Size Range: 0.19-0.03 mm**
33.3% silt **Major Axis Size Range: 0.12-0.02 mm**

Sample 14 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	9	7	0.09	0.07	0.02	Sand
	7	5	0.07	0.05	0.0114	Sand
	5	4	0.05	0.04	0.0065	Silt
	11	11	0.11	0.11	0.0396	Sand
	6	6	0.06	0.06	0.0118	Sand
	8	5	0.08	0.05	0.0131	Sand
	6	5	0.06	0.05	0.0098	Sand
	6	3	0.06	0.03	0.0059	Sand
	4	4	0.04	0.04	0.0052	Silt
	9	8	0.09	0.08	0.0236	Sand
	8	6	0.08	0.06	0.0157	Sand
	6	5	0.06	0.05	0.0098	Sand
	5	2	0.05	0.02	0.0033	Silt
	3	1	0.03	0.01	0.0010	Silt
	6	5	0.06	0.05	0.0098	Sand
	4	3	0.04	0.03	0.0039	Silt
	5	3	0.05	0.03	0.0049	Silt
	3	2	0.03	0.02	0.0020	Silt
	12	8	0.12	0.08	0.0314	Sand
	12	4	0.12	0.04	0.0157	Sand
	5	2	0.05	0.02	0.0033	Silt
	10	6	0.10	0.06	0.0196	Sand
	4	4	0.04	0.04	0.0052	Silt
	3	2	0.03	0.02	0.0020	Silt
	4	3	0.04	0.03	0.0039	Silt
	11	7	0.11	0.07	0.0252	Sand
	5	3	0.05	0.03	0.0049	Silt
	3	2	0.03	0 02	0.0020	Silt
	3	2	0.03	0.02	0.0020	Silt
	7	7	0.07	0.07	0.0160	Sand
Average (mm)	6.333	4.500	0.065	0 046	0.0093	
Median (mm)			0.06	0.04	0.0079	
Standard Deviation (mm)			0.029	0 024	0.010	

Sample 14 grains: 53% sand
47% silt

Major Axis Size Range: 0.12-0.03 mm
Minor Axis Size Range: 0.11-0.01 mm

Sample 16 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	17	9	0.17	0.09	0.05	Sand
	14	11	0.14	0.11	0.0504	Sand
	15	8	0.15	0.08	0.0393	Sand
	15	11	0.15	0.11	0.0540	Sand
	11	11	0.11	0.11	0.0396	Sand
	12	8	0.12	0.08	0.0314	Sand
	10	8	0.10	0.08	0.0262	Sand
	21	10	0.21	0.10	0.0687	Sand
	14	6	0.14	0.06	0.0275	Sand
	19	6	0.19	0.06	0.0373	Sand
	12	8	0.12	0.08	0.0314	Sand
	14	7	0.14	0.07	0.0321	Sand
	11	6	0.11	0.06	0.0216	Sand
	7	6	0.07	0.06	0.0137	Sand
	14	8	0.14	0.08	0.0366	Sand
	17	8	0.17	0.08	0.0445	Sand
	4	3	0.04	0.03	0.0039	Silt
	8	5	0.08	0.05	0.0131	Sand
	9	7	0.09	0.07	0.0206	Sand
	7	5	0.07	0.05	0.0114	Sand
	7	5	0.07	0.05	0.0114	Sand
	10	7	0.10	0.07	0.0229	Sand
	6	3	0.06	0.03	0.0059	Sand
	4	2	0.04	0.02	0.0026	Silt
	6	2	0.06	0.02	0.0039	Sand
	16	8	0.16	0.08	0.0419	Sand
	6	3	0.06	0.03	0.0059	Sand
	6	4	0.06	0.04	0.0079	Sand
	4	4	0.04	0.04	0.0052	Silt
	11	8	0.11	0.08	0.0288	Sand
Average (mm)	10.900	6.567	0.111	0.067	0.0234	
Median (mm)			0.11	0.07	0.0252	
Standard Deviation (mm)			0.048	0.026	0.018	

Sample 16 grains: 90% sand
10% silt

Major Axis Size Range: 0.21-0.04 mm
Minor Axis Size Range: 0.11-0.02 mm

Sample 17 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	18	12	0.18	0.12	0.07	Sand
	17	7	0.17	0.07	0.0389	Sand
	17	14	0.17	0.14	0.0779	Sand
	12	9	0.12	0.09	0.0353	Sand
	12	8	0.12	0.08	0.0314	Sand
	11	10	0.11	0.10	0.0360	Sand
	22	9	0.22	0.09	0.0648	Sand
	15	9	0.15	0.09	0.0442	Sand
	18	11	0.18	0.11	0.0648	Sand
	9	7	0.09	0.07	0.0206	Sand
	9	7	0.09	0.07	0.0206	Sand
	5	4	0.05	0.04	0.0065	Silt
	13	12	0.13	0.12	0.0510	Sand
	6	5	0.06	0.05	0.0098	Sand
	6	5	0.06	0.05	0.0098	Sand
	6	4	0.06	0.04	0.0079	Sand
	4	3	0.04	0.03	0.0039	Silt
	11	5	0.11	0.05	0.0180	Sand
	11	7	0.11	0.07	0.0252	Sand
	12	9	0.12	0.09	0.0353	Sand
	13	7	0.13	0.07	0.0298	Sand
	9	6	0.09	0.06	0.0177	Sand
	8	6	0.08	0.06	0.0157	Sand
	13	10	0.13	0.10	0.0425	Sand
	11	8	0.11	0.08	0.0288	Sand
	8	5	0.08	0.05	0.0131	Sand
	5	3	0.05	0.03	0.0049	Silt
	6	4	0.06	0.04	0.0079	Sand
	3	3	0.03	0.03	0.0029	Silt
	3	2	0.03	0.02	0.0020	Silt
Average (mm)	10.433	7.033	0.106	0.072	0.0240	
Median (mm)			0.11	0.07	0.0252	
Standard Deviation (mm)			0.050	0.031	0.021	

Sample 17 grains: 83% sand
17% silt

Major Axis Size Range: 0.22-0.03 mm
Minor Axis Size Range: 0.12-0.02 mm

Sample 18 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	15	9	0.15	0.09	0.04	Sand
	15	6	0.15	0.06	0.0294	Sand
	10	7	0.10	0.07	0.0229	Sand
	11	8	0.11	0.08	0.0288	Sand
	13	9	0.13	0.09	0.0383	Sand
	9	8	0.09	0.08	0.0236	Sand
	5	5	0.05	0.05	0.0082	Silt
	10	4	0.10	0.04	0.0131	Sand
	9	4	0.09	0.04	0.0118	Sand
	7	5	0.07	0.05	0.0114	Sand
	8	3	0.08	0.03	0.0079	Sand
	9	9	0.09	0.09	0.0265	Sand
	4	4	0.04	0.04	0.0052	Silt
	8	6	0.08	0.06	0.0157	Sand
	9	5	0.09	0.05	0.0147	Sand
	9	8	0.09	0.08	0.0236	Sand
	5	3	0.05	0.03	0.0049	Silt
	14	11	0.14	0.11	0.0504	Sand
	15	9	0.15	0.09	0.0442	Sand
	12	6	0.12	0.06	0.0236	Sand
	10	5	0.10	0.05	0.0164	Sand
	10	7	0.10	0.07	0.0229	Sand
	8	4	0.08	0.04	0.0105	Sand
	9	9	0.09	0.09	0.0265	Sand
	7	4	0.07	0.04	0.0092	Sand
	11	10	0.11	0.10	0.0360	Sand
	9	5	0.09	0.05	0.0147	Sand
	5	3	0.05	0.03	0.0049	Silt
	4	4	0.04	0.04	0.0052	Silt
	10	8	0.10	0.08	0.0262	Sand
Average (mm)	9 333	6.267	0.095	0.064	0.0191	
Median (mm)			0.09	0 06	0.0177	
Standard Deviation (mm)			0.032	0.024	0.013	

Sample 18 grains: 83% sand
17% silt

Major Axis Size Range: 0.15-0.04 mm
Minor Axis Size Range: 0.11-0.03 mm

Sample 19 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	12	11	0.12	0.11	0.04	Sand
	19	11	0.19	0.11	0.0684	Sand
	15	11	0.15	0.11	0.0540	Sand
	13	7	0.13	0.07	0.0298	Sand
	10	8	0.10	0.08	0.0262	Sand
	13	5	0.13	0.05	0.0213	Sand
	10	6	0.10	0.06	0.0196	Sand
	12	9	0.12	0.09	0.0353	Sand
	8	6	0.08	0.06	0.0157	Sand
	13	11	0.13	0.11	0.0468	Sand
	14	10	0.14	0.10	0.0458	Sand
	9	6	0.09	0.06	0.0177	Sand
	11	7	0.11	0.07	0.0252	Sand
	12	6	0.12	0.06	0.0236	Sand
	7	5	0.07	0.05	0.0114	Sand
	9	6	0.09	0.06	0.0177	Sand
	14	11	0.14	0.11	0.0504	Sand
	9	6	0.09	0.06	0.0177	Sand
	17	6	0.17	0.06	0.0334	Sand
	7	5	0.07	0.05	0.0114	Sand
	16	7	0.16	0.07	0.0366	Sand
	11	10	0.11	0.10	0.0360	Sand
	5	3	0.05	0.03	0.0049	Silt
	4	3	0.04	0.03	0.0039	Silt
	8	7	0.08	0.07	0.0183	Sand
	8	7	0.08	0.07	0.0183	Sand
	9	8	0.09	0.08	0.0236	Sand
	9	6	0.09	0.06	0.0177	Sand
	12	7	0.12	0.07	0.0275	Sand
	8	5	0.08	0.05	0.0131	Sand
Average (mm)	10.800	7.200	0.110	0.073	0.0254	
Median (mm)			0.11	0.07	0.0240	
Standard Deviation (mm)			0.035	0.024	0.015	

Sample 19 grains: 93% sand
7% silt

Major Axis Size Range: 0.19-0.04 mm
Minor Axis Size Range: 0.11-0.03 mm

Sample 20 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	19	10	0.19	0.10	0.06	Sand
	15	9	0.15	0.09	0.0442	Sand
	20	7	0.20	0.07	0.0458	Sand
	11	9	0.11	0.09	0.0324	Sand
	6	4	0.06	0.04	0.0079	Sand
	4	3	0.04	0.03	0.0039	Silt
	12	11	0.12	0.11	0.0432	Sand
	8	8	0.08	0.08	0.0209	Sand
	15	4	0.15	0.04	0.0196	Sand
	10	7	0.10	0.07	0.0229	Sand
	16	5	0.16	0.05	0.0262	Sand
	10	6	0.10	0.06	0.0196	Sand
	13	10	0.13	0.10	0.0425	Sand
	9	7	0.09	0.07	0.0206	Sand
	5	3	0.05	0.03	0.0049	Silt
	5	5	0.05	0.05	0.0082	Silt
	12	8	0.12	0.08	0.0314	Sand
	6	3	0.06	0.03	0.0059	Sand
	9	5	0.09	0.05	0.0147	Sand
	4	2	0.04	0.02	0.0026	Sand
	15	10	0.15	0.10	0.0491	Sand
	2	2	0.02	0.02	0.0013	Silt
	5	3	0.05	0.03	0.0049	Silt
	5	2	0.05	0.02	0.0033	Silt
	5	3	0.05	0.03	0.0049	Silt
	8	6	0.08	0.06	0.0157	Sand
	6	2	0.06	0.02	0.0039	Sand
	9	4	0.09	0.04	0.0118	Sand
	5	5	0.05	0.05	0.0082	Silt
	3	3	0.03	0.03	0.0029	Silt
Average (mm)	9.067	5.533	0.093	0.056	0.0164	
Median (mm)			0.09	0.05	0.0139	
Standard Deviation (mm)			0.049	0.029	0.017	

Sample 20 grains: 70% sand
30% silt

Major Axis Size Range: 0.20-0.02 mm
Minor Axis Size Range: 0.11-0.02 mm

Sample 21 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	12	10	0.12	0.10	0.04	Sand
	9	8	0.09	0.08	0.0236	Sand
	15	8	0.15	0.08	0.0393	Sand
	10	7	0.10	0.07	0.0229	Sand
	10	7	0.10	0.07	0.0229	Sand
	12	8	0.12	0.08	0.0314	Sand
	14	4	0.14	0.04	0.0183	Sand
	3	2	0.03	0.02	0.0020	Silt
	8	6	0.08	0.06	0.0157	Sand
	11	6	0.11	0.06	0.0216	Sand
	6	6	0.06	0.06	0.0118	Sand
	7	4	0.07	0.04	0.0092	Sand
	12	5	0.12	0.05	0.0196	Sand
	10	5	0.10	0.05	0.0164	Sand
	6	3	0.06	0.03	0.0059	Sand
	6	6	0.06	0.06	0.0118	Sand
	9	4	0.09	0.04	0.0118	Sand
	5	2	0.05	0.02	0.0033	Silt
	3	2	0.03	0.02	0.0020	Silt
	5	3	0.05	0.03	0.0049	Silt
	12	3	0.12	0.03	0.0118	Sand
	7	4	0.07	0.04	0.0092	Sand
	5	4	0.05	0.04	0.0065	Silt
	5	2	0.05	0.02	0.0033	Silt
	7	3	0.07	0.03	0.0069	Sand
	7	7	0.07	0.07	0.0160	Sand
	2	1	0.02	0.01	0.0007	Silt
	9	4	0.09	0.04	0.0118	Sand
	10	4	0.10	0.04	0.0131	Sand
	3	2	0.03	0.02	0.0020	Silt
Average (mm)	8.000	4.667	0.082	0.048	0.0122	
Median (mm)			0.08	0.04	0.0098	
Standard Deviation (mm)			0.035	0.023	0.010	

Sample 21 grains: 73% sand
27% silt

Major Axis Size Range: 0.15-0.02 mm
Minor Axis Size Range: 0.10-0.01 mm

Sample 22 Photographic grain measurements

	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	20	5	0.20	0.05	0.03	Sand
	15	10	0.15	0.10	0.0491	Sand
	5	5	0.05	0.05	0.0082	Silt
	14	6	0.14	0.06	0.0275	Sand
	7	5	0.07	0.05	0.0114	Sand
	7	5	0.07	0.05	0.0114	Sand
	10	5	0.10	0.05	0.0164	Sand
	7	3	0.07	0.03	0.0069	Sand
	8	6	0.08	0.06	0.0157	Sand
	6	6	0.06	0.06	0.0118	Sand
	7	5	0.07	0.05	0.0114	Sand
	7	3	0.07	0.03	0.0069	Sand
	3	2	0.03	0.02	0.0020	Silt
	8	5	0.08	0.05	0.0131	Sand
	5	3	0.05	0.03	0.0049	Silt
	5	2	0.05	0.02	0.0033	Silt
	8	4	0.08	0.04	0.0105	Sand
	3	3	0.03	0.03	0.0029	Silt
	3	2	0.03	0.02	0.0020	Silt
	8	4	0.08	0.04	0.0105	Sand
	14	5	0.14	0.05	0.0229	Sand
	5	3	0.05	0.03	0.0049	Silt
	8	3	0.08	0.03	0.0079	Sand
	7	6	0.07	0.06	0.0137	Sand
	8	4	0.08	0.04	0.0105	Sand
	2	1	0.02	0.01	0.0007	Silt
	4	3	0.04	0.03	0.0039	Silt
	16	11	0.16	0.11	0.0576	Sand
	6	3	0.06	0.03	0.0059	Sand
	4	3	0.04	0.03	0.0039	Silt
Average (mm)	7.667	4.367	0.078	0.045	0.0110	
Median (mm)			0.07	0.04	0.0092	
Standard Deviation (mm)			0.043	0.022	0.013	

Sample 22 grains: 66.7% sand
33.3% silt

Major Axis Size Range: 0.20-0.02 mm
Minor Axis Size Range: 0.11-0.01 mm

Sample 23 Photographic grain measurements						
	Major Axis Measured (mm)	Minor Axis Measured (mm)	Major Axis Actual (mm)	Minor Axis Actual (mm)	Area (mm^2)	Geotechnical Classification
	10	7	0.10	0.07	0.02	Sand
	8	4	0.08	0.04	0.0105	Sand
	7	4	0.07	0.04	0.0092	Sand
	8	6	0.08	0.06	0.0157	Sand
	7	4	0.07	0.04	0.0092	Sand
	5	4	0.05	0.04	0.0065	Silt
	4	4	0.04	0.04	0.0052	Silt
	4	3	0.04	0.03	0.0039	Silt
	11	5	0.11	0.05	0.0180	Sand
	8	6	0.08	0.06	0.0157	Sand
	4	2	0.04	0.02	0.0026	Silt
	5	5	0.05	0.05	0.0082	Silt
	6	2	0.06	0.02	0.0039	Sand
	4	1	0.04	0.01	0.0013	Silt
	6	4	0.06	0.04	0.0079	Sand
	4	3	0.04	0.03	0.0039	Silt
	3	2	0.03	0.02	0.0020	Silt
	5	4	0.05	0.04	0.0065	Silt
	10	4	0.10	0.04	0.0131	Sand
	4	2	0.04	0.02	0.0026	Silt
	6	5	0.06	0.05	0.0098	Sand
	8	2	0.08	0.02	0.0052	Sand
	12	9	0.12	0.09	0.0353	Sand
	10	8	0.10	0.08	0.0262	Sand
	7	4	0.07	0.04	0.0092	Sand
	14	7	0.14	0.07	0.0321	Sand
	8	5	0.08	0.05	0.0131	Sand
	2	2	0.02	0.02	0.0013	Silt
	7	3	0.07	0.03	0.0069	Sand
	9	7	0.09	0.07	0.0206	Sand
Average (mm)	6.867	4.267	0.070	0.044	0.0096	
Median (mm)			0.07	0.04	0.0092	
Standard Deviation (mm)			0.029	0.020	0.009	

Sample 23 grains: 63% sand
37% silt

Major Axis Size Range: 0.14-0.02 mm
Minor Axis Size Range: 0.09-0.01 mm

APPENDIX H

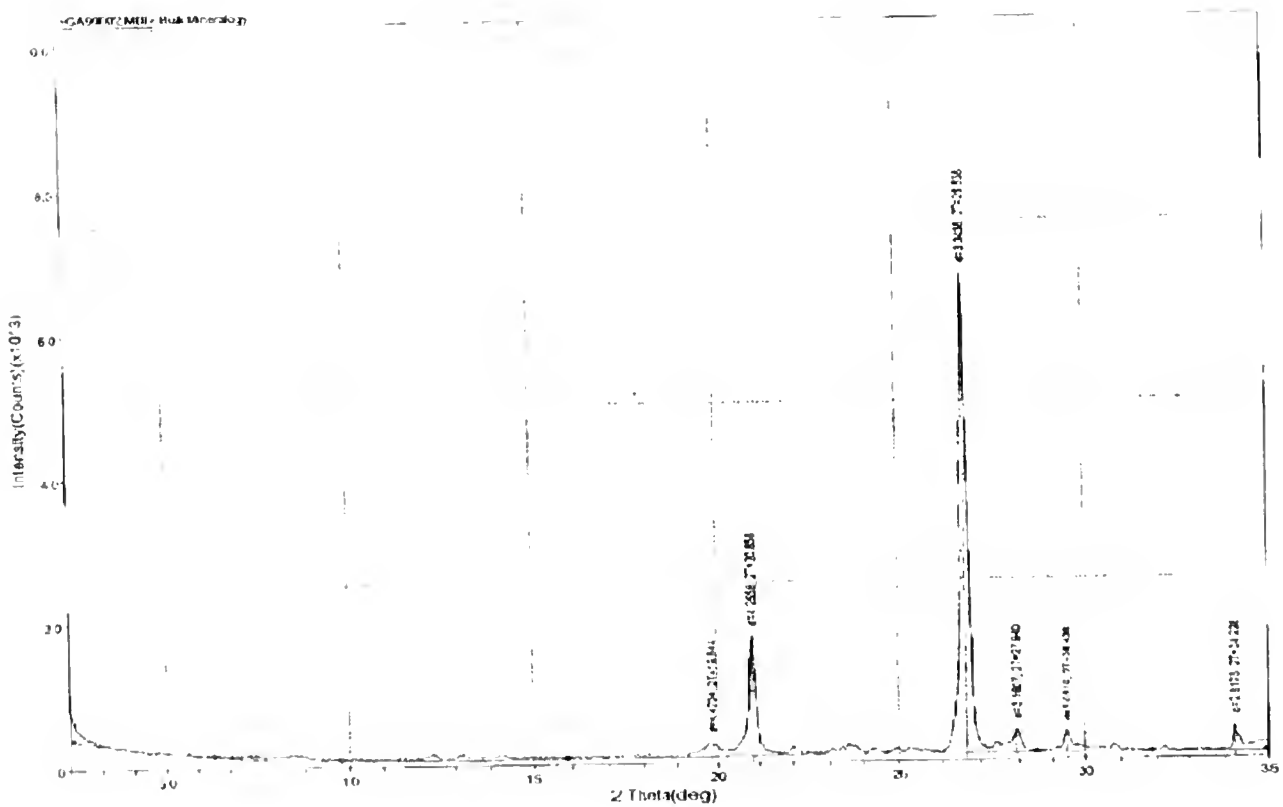
X-RAY DIFFRACTION ANALYSIS

Kiva Q Finishes

Cliff Palace

Mesa Verde National Park

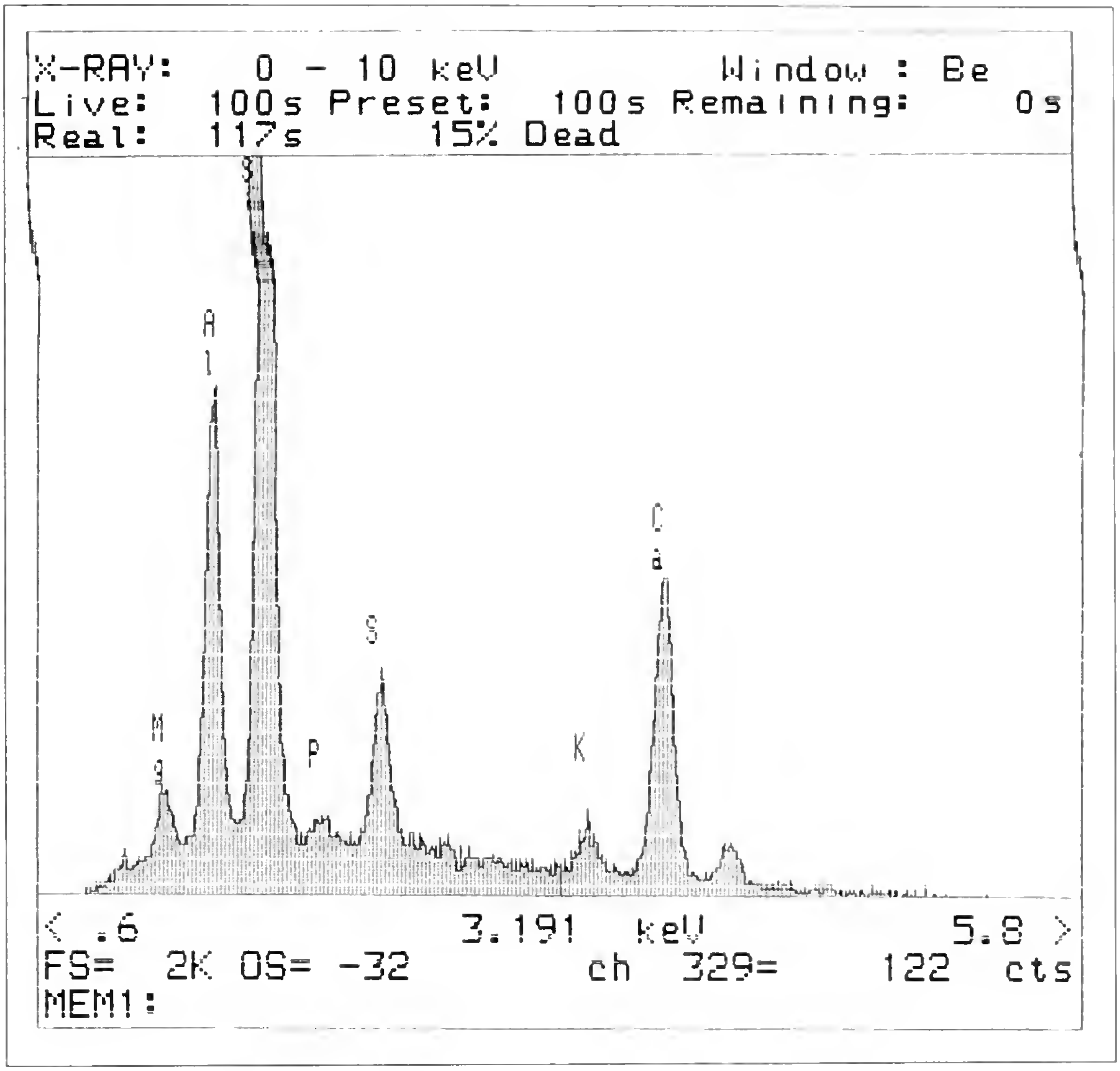
X-RAY DIFFRACTOGRAM
KIVA Q FINISHES BULK MINERALOGY
Cliff Palace
Mesa Verde National Park



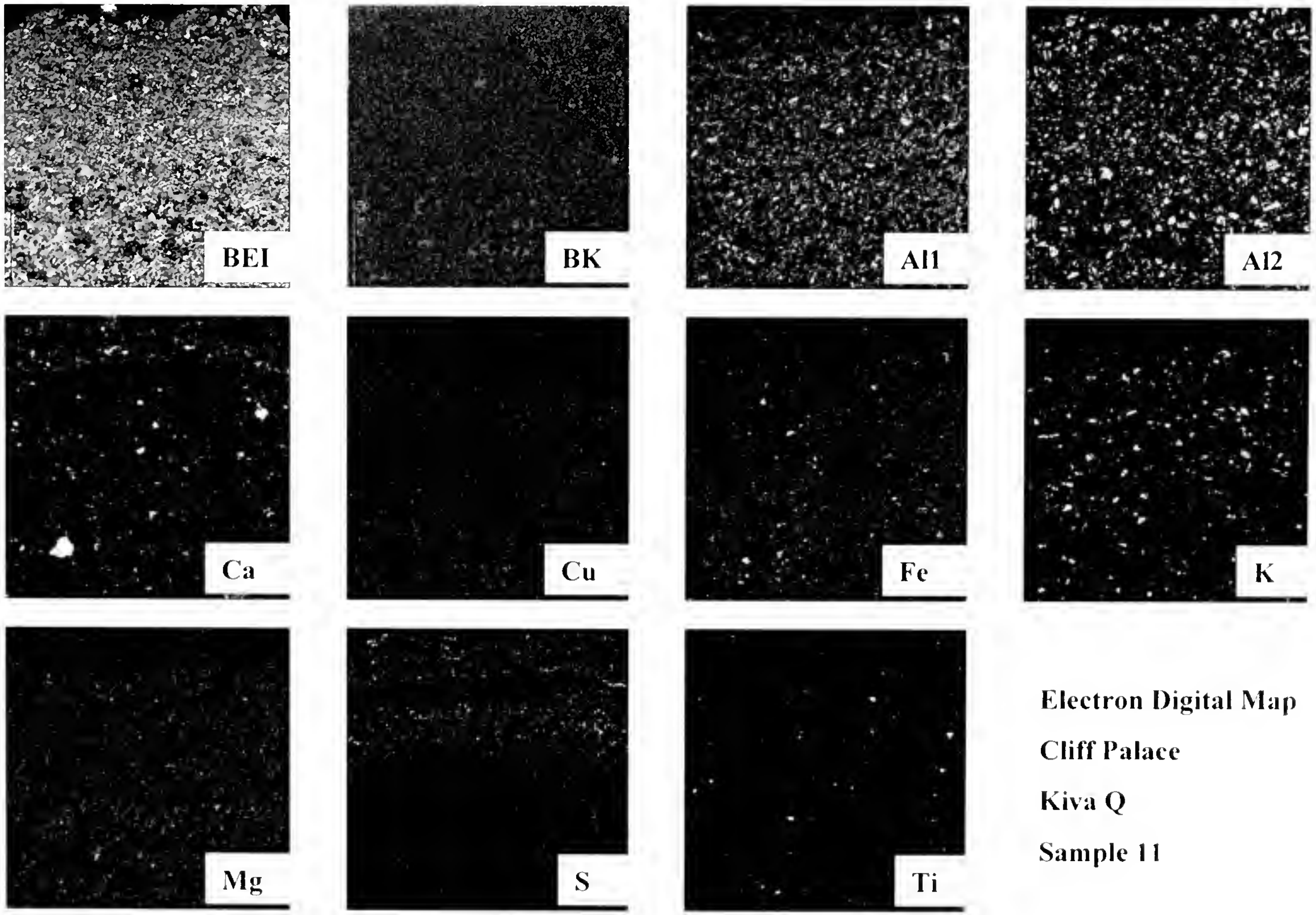
APPENDIX I

SCANNING ELECTRON MICROSCOPY

Electron Digital Maps



SEM/EDS Spectrum of Sample 11, Kiva Q

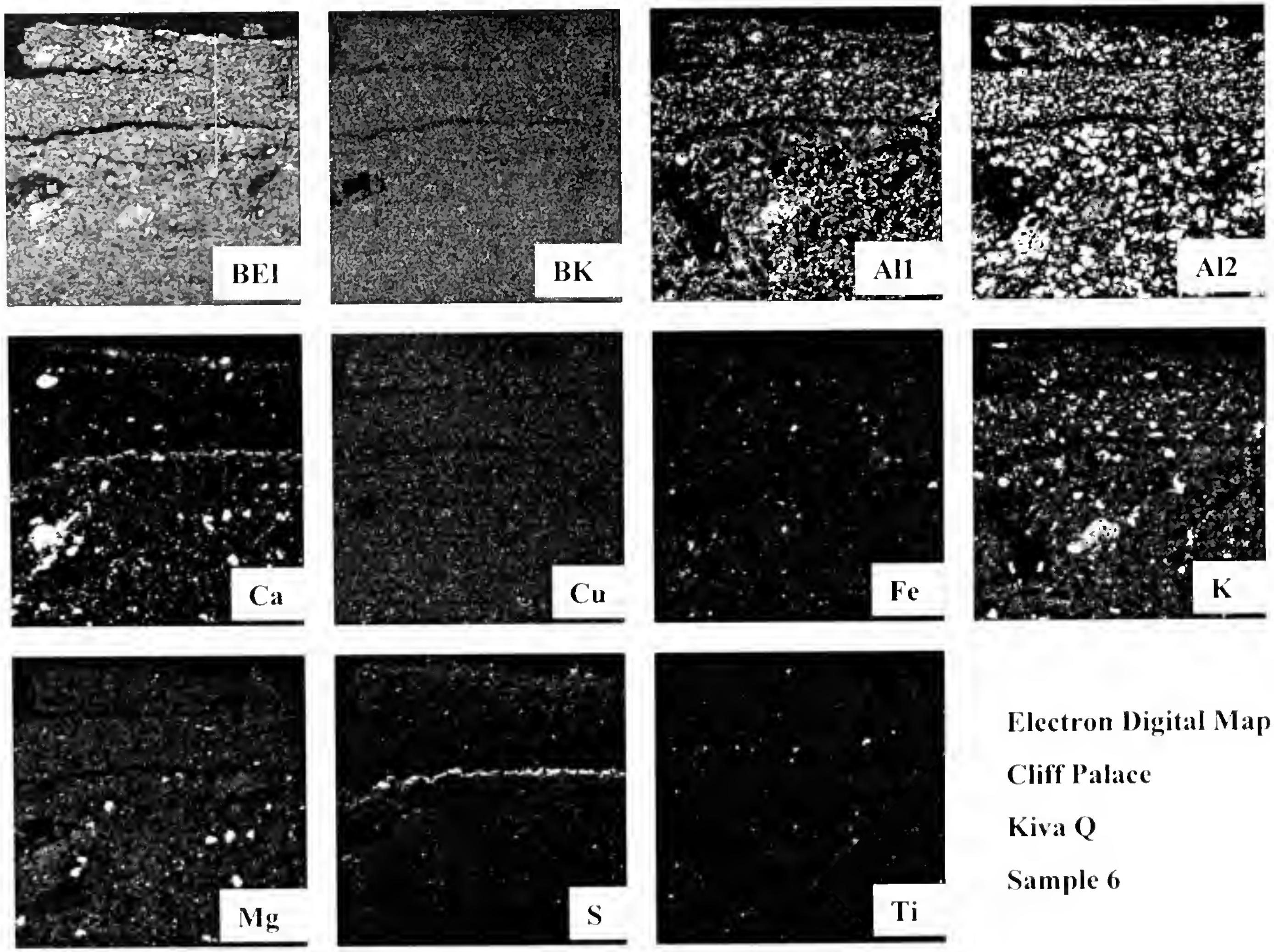


Electron Digital Map

Cliff Palace

Kiva Q

Sample 11



Electron Digital Map

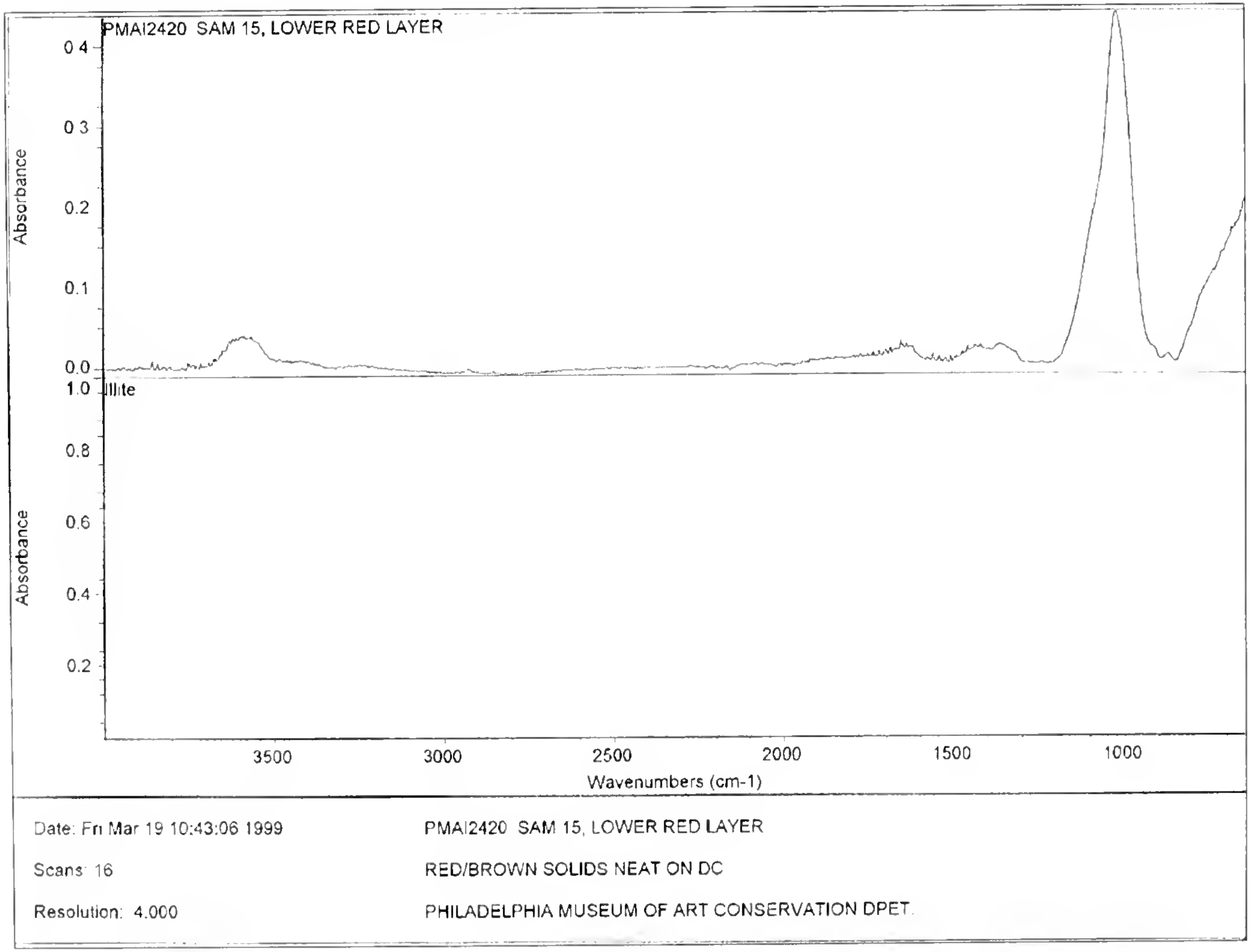
Cliff Palace

Kiva Q

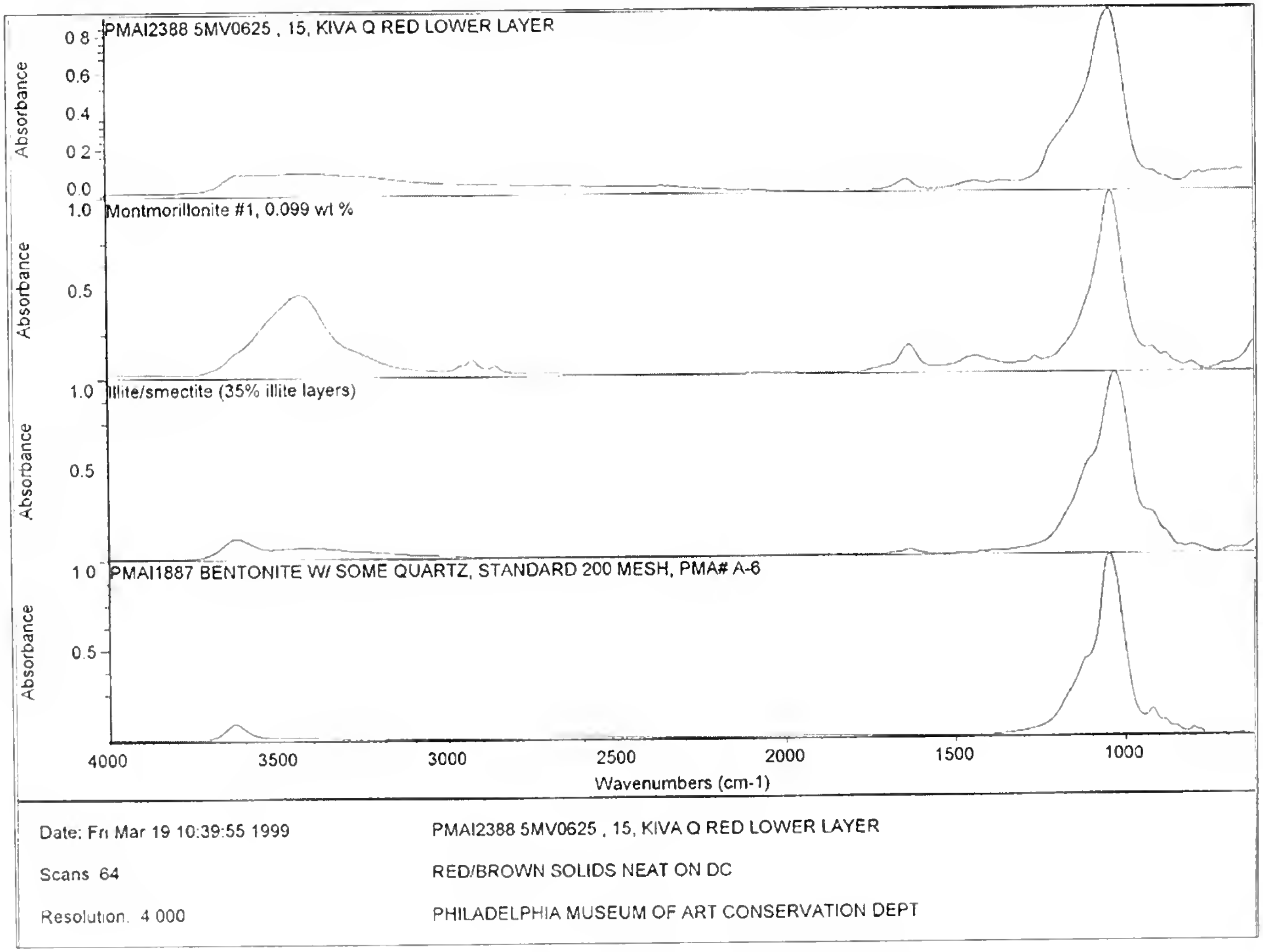
Sample 6

APPENDIX J

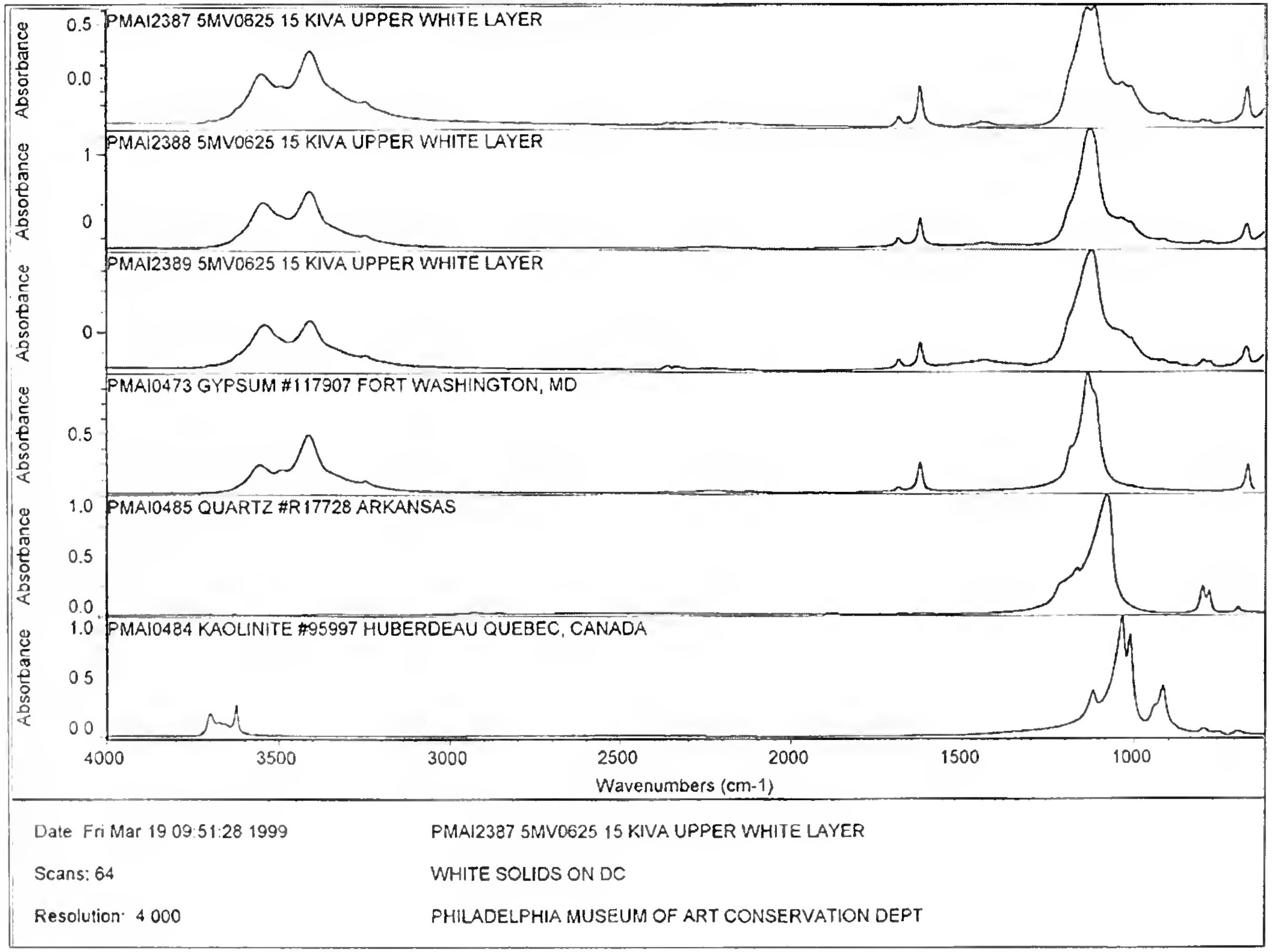
FOURIER TRANSFER INFRARED SPECTROSCOPY



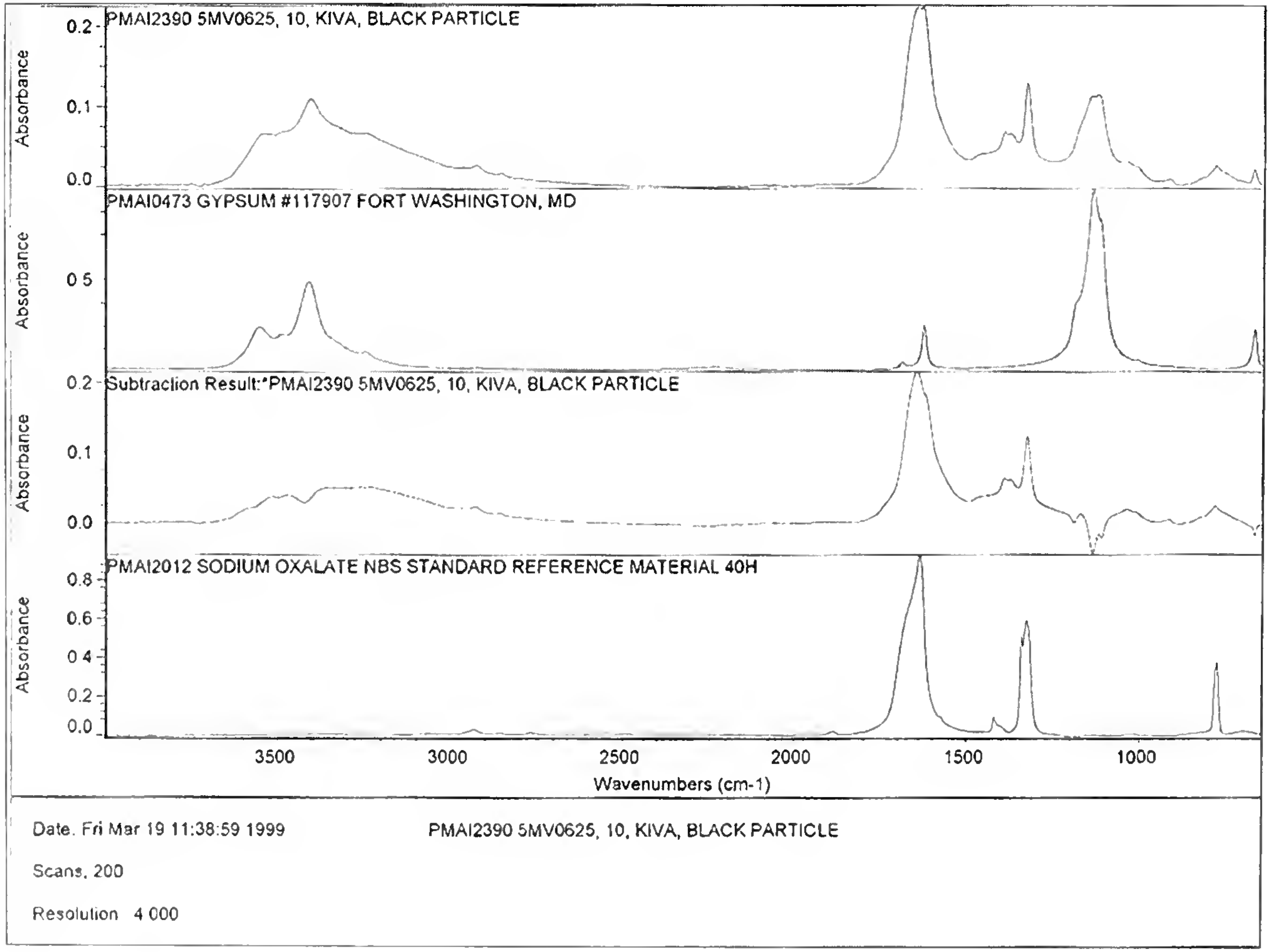
Infrared Spectrum of base plaster from Sample 15, Kiva Q



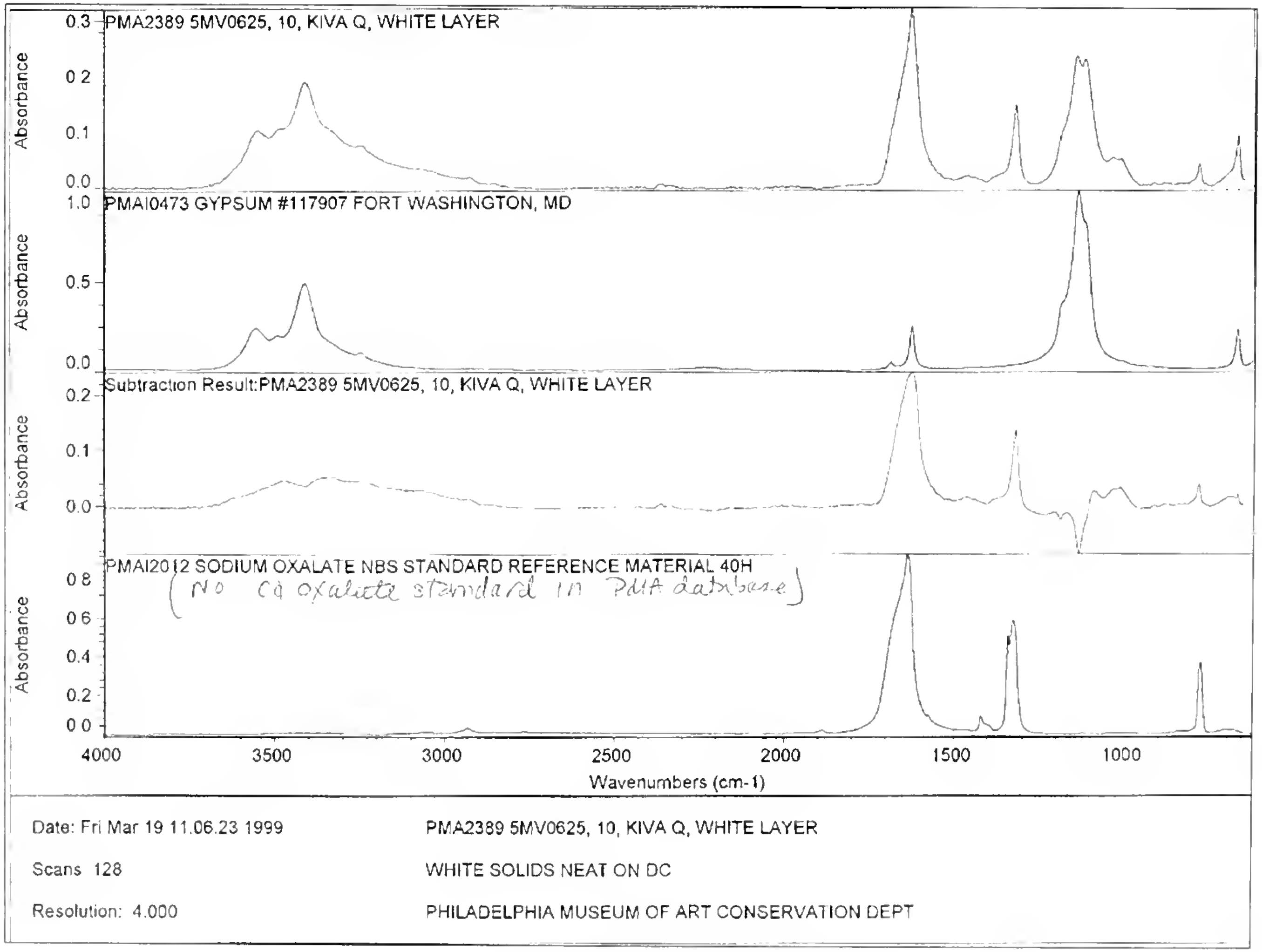
Infrared Spectrum of base plaster from Sample 15, Kiva Q



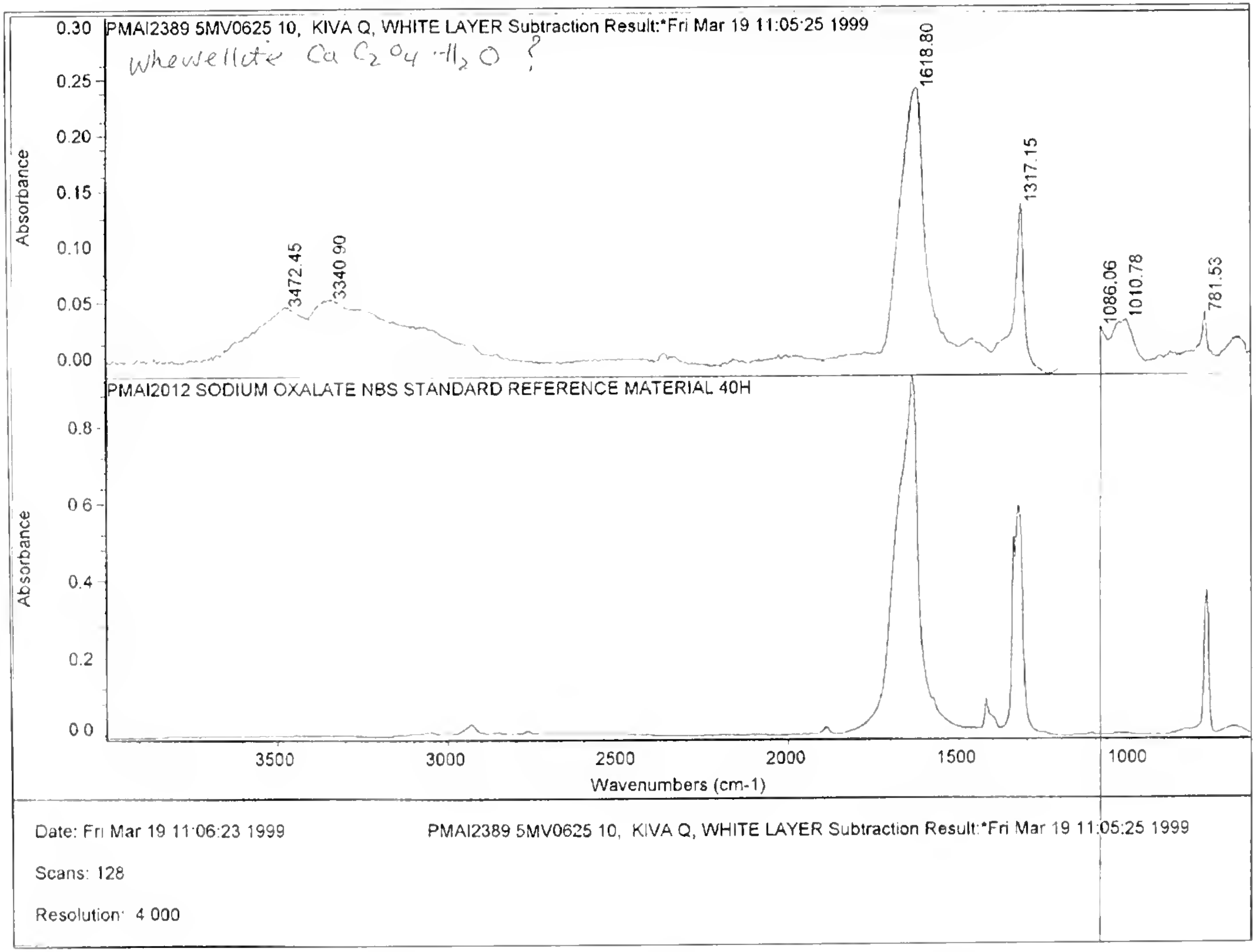
Infrared Spectrum of white pigment from Sample 15, Kiva Q



Infrared Spectrum of black pigment from Sample 10, Kiva Q



Infrared Spectrum of white pigment from Sample 10, Kiva Q



Infrared Spectrum of white pigment from Sample 10, Kiva Q

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